



STANDARD METHODOLOGY FOR ASSESSMENT OF RANGE OF MOTION WHILE WEARING BODY ARMOR

by
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14. ABSTRACT This document outlines the methodology used to collect data in an evaluation examining the range of motion (ROM) of 115 Soldiers and Airmen conducted by the Natick Soldier Research, Development and Engineering Center in 2011. The purpose of the evaluation was to better understand the performance impact of body armor on U.S. military warfighters. Traditionally, ROM has been used to assess the impact on performance that individuals experience after an injury or illness. It was used in this case to determine the impact on performance that individuals experienced when they performed the standardized movements in a variety of body armor systems and duty uniform. When assessing ROM, while test participants are wearing clothes/equipment, modifications need to be made. The document contains the following information for conducting and evaluating 26 specific movements: test equipment needed, description of the movement, description of the measurement, cautions, potential causes of restriction, real world equivalent activities associated with the movement, and the form the data should be collected in and any manipulation. Basic movements included focused on base neck, spine, shoulder, and hips. Mission movements/activities included aiming a weapon, box lifts, high knees, and trunk flexions. For each movement, summary statistics and percentiles are given for the baseline configuration (duty uniform, boots, t-shirt, personal undergarments, and riggers belt).						
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STANDARD METHODOLOGY FOR ASSESSMENT OF RANGE OF MOTION WHILE WEARING BODY ARMOR

1. INTRODUCTION

Body armor systems have been developed to provide ballistic protection for military personnel from enemy threats. There is a need to recognize, however, that while body armor provides essential protection it can also interfere with an individual's ability to maneuver in order to accomplish mission critical tasks and activities. Therefore, it is important to evaluate body armor systems to ensure that mobility is not compromised to the point where mission performance is degraded to an unacceptable level.

This document summarizes a project performed by the Natick Soldier Research, Development and Engineering Center (NSRDEC), between January 2011 and March 2012, to develop and analyze a comprehensive set of movements to predict a warfighter's ability to maneuver while performing various mission critical tasks when wearing different armor systems. The purposes were (1) to describe the most basic and influential movements that Soldiers make while completing their daily missions in combat environments and (2) to provide a repeatable, consistent method to measure range of motion (ROM) and inform designers, researchers, and testers on the effects of specific body armor systems on individual ROM, mobility, and reach. There are unique movements and tasks associated with each job and mission. The effort described here focused on the most common across the aviation, mounted, and dismounted arenas, with the most intense focus on the dismounted community.

Through the development of the ROM test methodology, valuable data were generated that could:

1. Inform the public on the ROMs of military personnel while in a duty uniform.
2. Provide data to be input into computer generated models of the body.

Soldiers' ROM was measured while wearing the body armor systems available at the time of the data collection (in 2011). This report examines or captures the effects of the armor only, without any influence/impact by any other equipment or ancillary gear worn. Additionally, the focus of this document is on how the body armor affects the torso, and therefore extremity armor was not included, with the exception of the collar and yoke.

Configurations were based on the Army's establishment of Body Armor Protection Levels (BAPLs) (Maneuver Center of Excellence, 13 October 2010, subject: Body Armor Protection Levels). The BAPLs were:

- BAPL 0: No body armor worn
- BAPL 1: Vest or plate carrier with soft armor only
- BAPL 2: Plate carrier with front and back plates
- BAPL 3: Plate carrier with front, back, and side plates
- BAPL 4: Improved outer tactical vest (IOTV) with front and back plates
- BAPL 5: IOTV with front, back, and side plates

A year of planning preceded this data collection effort. During that time, a large variety of candidate measurements were assessed to determine those that were the most impacted by body armor and were the most relevant (in terms of frequency and importance) to the Soldier mission. Additionally, the more complex movements were broken down into a series of basic movements.

Chapter 2 of this report describes the baseline and armor system components, test instruments, data collection and analysis techniques, and the demographic background and military experience of the test participants used in the evaluation. Chapter 3 summarizes the terminology and concepts associated with ROM measurements and the two basic anthropometric postures used as the starting points for the specific movements. Chapter 4 describes the data collection template that should be used and any analysis that needs to be performed for the movements that were chosen and outlines and breaks down each of those movements to describe how it is performed, how it is measured, the particular pitfall(s) the data collector must be aware of, the relevant body area, the potential causes of restriction (in terms of the design of the body armor), and the real world (or controlled) movements it relates to. A total of 26 movements (18 objectively scored and 8 subjectively scored) are described in Chapter 4:

Objectively Scored:

- Cervical Rotation
- Forward Five Steps
- High Knee/ Knee Lift
- Overhead Fingertip Reach
- Seated Stature
- Standing Stature
- Thoracic/ Lumbar Spine Lateral Flexion
- Thoracic/ Lumbar Spine Rotation
- Trunk Flexion – Seated
- Trunk Flexion - Standing
- Upper Arm/ Shoulder Abduction
- Upper Arm/ Shoulder Backward Extension
- Upper Arm/ Shoulder Cross Body Extension (while seated)
- Upper Arm/ Shoulder Cross Body Reach

- Upper Arm/ Shoulder Forward Extension
- Upper Arm/Shoulder Forward Extended Reach
- Upper Leg/ Hip Flexion
- Ventral-Dorsal Cervical Flexion

Subjectively Scored:

- Box Lift
- Jog
- Stand – Prone – Stand
- Take a Knee
- Target Acquisition/Aim Weapon
 - Kneel with M4
 - Prone with M4
 - Stand with 9mm
 - Stand with M4

These movements are all components of the mission critical movements that make up the daily duties and missions of the US Army Soldier. Each of the 18 objective movements include performance data for the baseline configuration. The subjective movements are not measured with quantifiable criteria. They are evaluated using various pass/fail or yes/no observation criteria. No summaries of the subjective data are included in this report, only a description of the movement. Chapter 5 summarizes the purpose of the data presented in Chapter 4 and ways it can be used.

2. METHODS

2.1 Test Configurations

Original configurations were chosen based on BAPLs, and BAPL 0 was considered the baseline configuration because no body armor was worn. Test participants wore their service specific duty uniform (the Army Combat Uniform (ACU), the Army Aircrew Combat Uniform (A2CU), or the Airman Battle Uniform (ABU)) with their duty boots, personal undergarments, t-shirt, and riggers belt.

Test configurations were based on currently fielded US Army body armor systems. This evaluation was not designed to be an assessment of these body armor systems and designs. Instead, each of these systems was chosen to be representative of a category of body armor (i.e., plate carrier). Configurations were chosen based on a subset of the BAPLs. Other than the collar and yoke, no extremity armor pieces were added. No gear was mounted on the armor for this evaluation, in an effort to isolate the degradations caused by the armor itself (as opposed to ancillary equipment). The test configurations were:

- BAPL 0: No body armor worn, duty uniform (either Army Combat Uniform (ACU), Army Aircrew Combat Uniform (A2CU), or Airman Battle Uniform (ABU)) with duty boots, personal undergarment, t-shirt, and riggers belt
- BAPL 1: IOTV (Figure 1, left) with soft armor only (no plates), collar and yoke add-on component, and all components of BAPL 0
- BAPL 3: Soldier Plate Carrier System (SPCS) (Figure 1, right) with Enhanced Small Arms Protective Insert (ESAPI) plates (Figure 2) in front and back, Enhanced Side Ballistic Insert (ESBI) side plates (Figure 3), and all components of BAPL 0
- BAPL 5: IOTV with ESAPI plates in front and back, ESBI side plates, collar and yoke add-on component, and all components of BAPL 0



IOTV



SPCS

**Figure 1: Body armor systems. Left: IOTV, used in BAPLs 1 and 5;
Right: SPCS, used in BAPL 3**

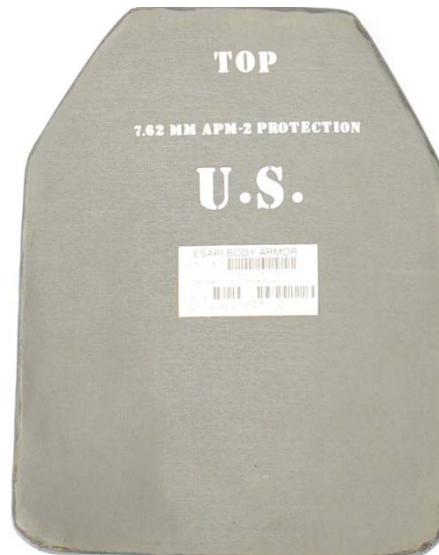


Figure 2: ESAPI, used in BAPLs 3 and 5



Figure 3: ESBI, or side plates, used in BAPLs 3 and 5

2.2 Test Instruments

Several standard instruments were used in addition to a few unique tools that were created for this data collection effort.

The Acumar Digital Inclinometer (Figure 4) was the primary tool used to measure joint angle change. However, for certain measurements (as described in Chapter 4), the digital inclinometer was unable to capture the plane of movement correctly, due to the placement of the accelerometers within the device, and instead the Unilevel Inclinometer (Figure 5) or the Lafayette Gollehon Extendable Goniometer (Figure 6) was used. For example, Thoracic/Lumbar Spine Rotation was measured using the extendable goniometer because there was no way to position the digital inclinometer to properly capture the side-to-side movement of the test participant; the extendable goniometer allowed that movement to be captured more accurately.

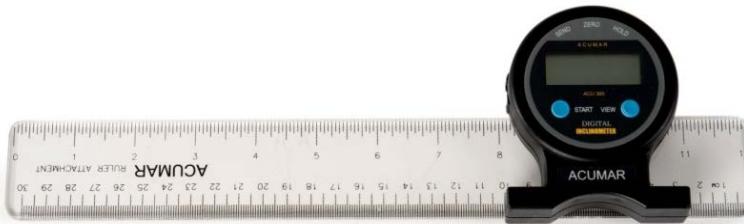


Figure 4: Acumar Digital Inclinometer ACU 360 with Ruler attachment (digital inclinometer)



Figure 5: Unilevel Inclinometer (gravity inclinometer)

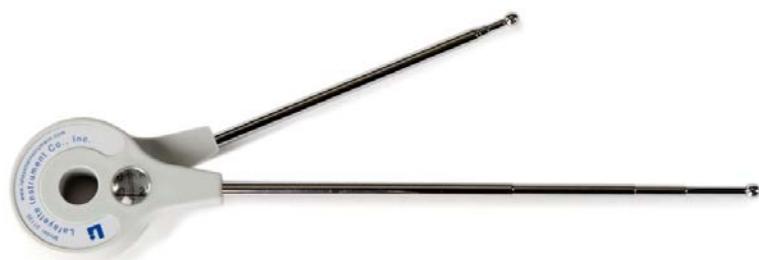


Figure 6: Lafayette Gollehon Extendable Goniometer (protractor goniometer)

An anthropometer (Figure 7) and steel tape (Figure 8) were used to collect anthropometric measurements on the test participants, primarily stature (standing and seated) and chest circumference.

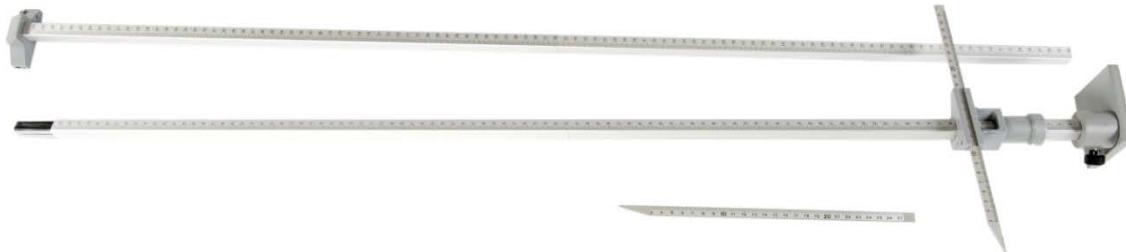


Figure 7: GPM Anthropometer Model 101 (partially assembled) with base plate, 0-2100mm



Figure 8: Lufkin 6mm x 2m Executive® Diameter Pocket Steel Tape

A variety of scales were used for the reaches and mission movements. All were designed similar to graph paper, with 1 mm blocks, and thicker outlines at every 5, 10, and 100 mm mark. The scales differed primarily in how they were mounted. The vertical wall scale (Figure 9) was mounted against a wall that was 3 m high. The wall was stable enough to support a person in body armor leaning against it. A level was used to ensure that the scale was hung straight.

The floor scale (Figure 10) was set on a flat floor of approximately 10-11 m long. Ideally, the scale was on a solid surface, although thin industrial carpeting was also used, as long as the backing had minimal padding and did not impact the measurements. Both the vertical and floor scales were broken into separate pieces, which could be connected. They were 110 cm long (with 10 cm for overlapping with the next piece) and 45 cm wide. All pieces were laminated so they could be written on with washable markers. When possible (depending on the data collection location), the “0” mark was placed against the baseboard of a wall.



Figure 9: Vertical wall scale (with close up)

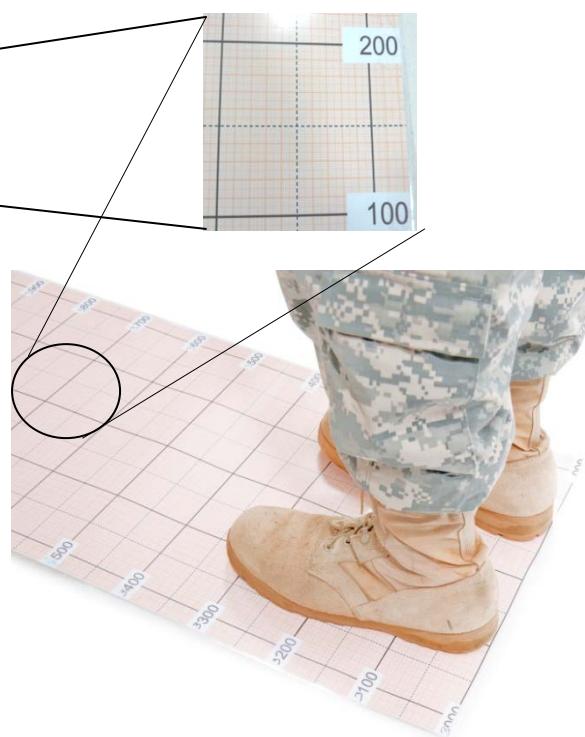


Figure 10: Floor scale (with close up)

The horizontal wall scale (Figure 11) was affixed to a wall that was at least the length and width of the scale. The scale was 110 cm wide and 50 cm tall. This scale started at 30 cm (i.e., 30 cm away from the corner of two walls) so that the right arm of the participant rested against the wall when he/she stood against the perpendicular wall, as depicted in Figure 11. A level was used to ensure that the scale was hung straight.

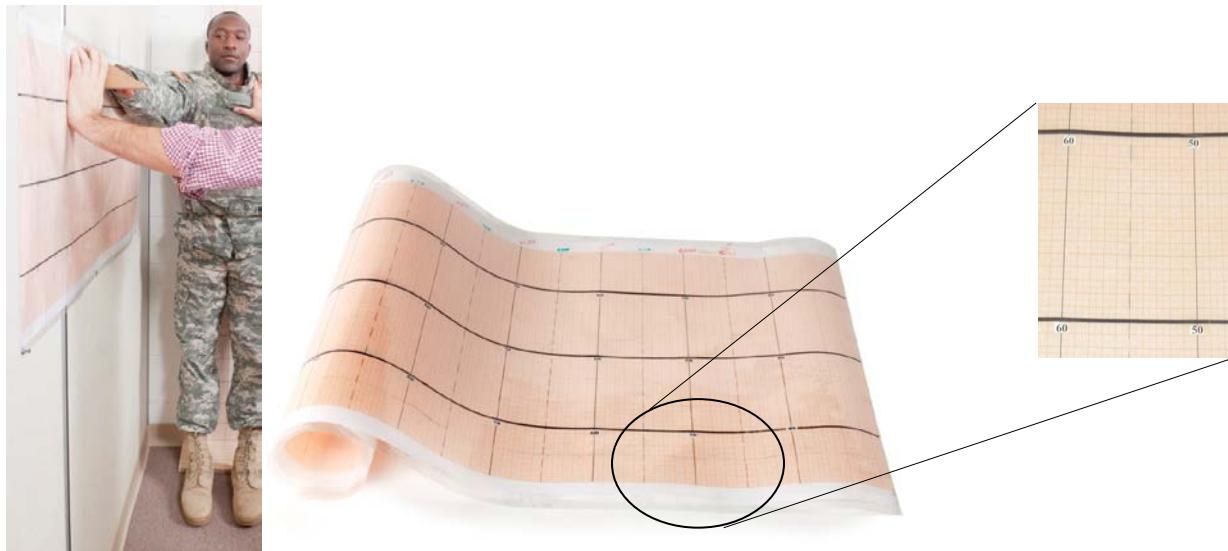


Figure 11: Horizontal wall scale (in use and with close up)

For many of the reach measurements, the test participant must stand with heels or toes 20 cm away from the wall. A block of wood (Figure 12) was created to force that 20 cm difference between the test participant's heel and the wall. A second block of wood, in the shape of a right angle scalene triangle (Figure 13), was used by the tester to place against the measurement scale. A variety of rulers, meter sticks (Figure 14), and T square rulers (Figure 15) were used as well. All rulers and meter sticks had cm and mm marks on them.



Figure 12: 20 cm block



Figure 13: Measuring block



Figure 14: Meter stick (with close up)

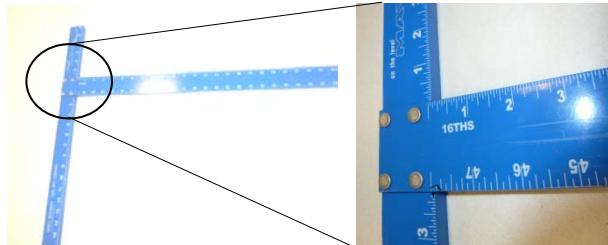


Figure 15: T square ruler (with close up)

Platforms were needed for the trunk flexion measurements, since many of the test participants were able to reach past their feet when performing the task. A plyometric box platform (Figure 16) was used for standing measurements, and a custom designed platform (Figure 17) was designed that could hold a folding chair for seated measurements. A variety of seats were used for the various measurements: chairs with arms and a back, chairs with a back but without arms (e.g., a folding chair), and seats without arms or a back (e.g., a stool). A step ladder was used for testers when they had to be above the participants (e.g., overhead reaches, cross body reaches).



Figure 16: Biokinetic plyometric box (18 in)



Figure 17: Raised platform used to place chair on

For the box lift, a medium sized box was used. It was 38 cm high, 34.5 cm wide, and 24 cm deep. It was very light, weighing between 1 and 2 lb. No targets were used for aiming the weapons; instead, test participants were told to aim straight ahead. The focus was on the interface between the weapon, the test participant, and the body armor.

2.3 Test Data Collection and Analysis

The test participants were processed through a number of stations: in-processing (briefing and demographic questionnaire); fit, size, and anthropometry; goniometer measurements; reach measurements; and mission movements (Figure 18). Each participant completed as many armor configurations as possible in a 4 h period. Five to seven participants were processed at a time.

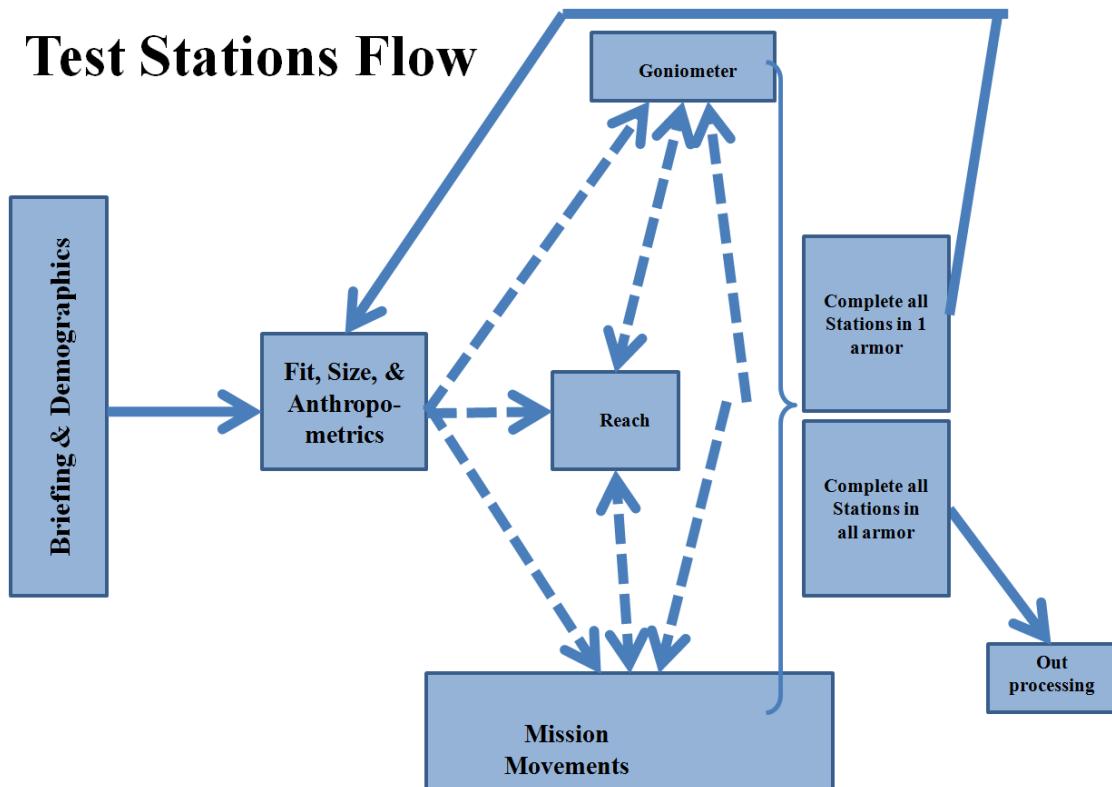


Figure 18: Participant flow through test stations

The order of presentation of the configurations was determined based on armor sizes available, as an attempt to keep the flow of participants going through the station in the most orderly manner and have a quasi-random order of presentation of BAPL order across the participants. They could be started in any one of the four test configurations.

During the in-processing, the participants were briefed on the purpose of the study and what they were going to do during the session. Once briefed, the participants were given a demographic and background questionnaire that asked them about themselves (age, rank, service, number of combat tours) and their background and experience with body armor.

Chest circumference was measured for all the participants, and they were outfitted in their best fitting body armor size. To identify the correctly fitting size, the participants tried on the size

identified in the Interceptor Body Armor (IBA) OTV size prediction chart based on their chest circumference (Table 1). Sizes extra-small through extra-large (in regular lengths) were available in all the armor systems.

Table 1: Size prediction chart for IBA OTV

Size	Extra Small	Small	Medium	Large	Extra Large
mm	737-838	838-940	940-1041	1041-1143	1143-1245
in	29-33	33-37	37-41	41-45	45-49

The participants tried on alternate sizes until the best fitting size was identified. Best fitting size was determined by a trained anthropometrist, who assessed the fit based on specific fit criteria, including chest circumference, plate location, vest length, adjustability, and overlap criteria (if defined by the armor design criteria). In addition, the participants were asked to perform some basic movements in the armor, including standing, turning, and sitting. After this was conducted, a fit rating was given for the best fitting armor system.

Participants were only used if they could acceptably (as determined by the tester) fit into the armor system. Additionally, at the Fit, Size, and Anthropometrics station, the participants' standing and seated statures were measured both with and without boots on for all the configurations, including BAPL 0. The purpose of taking measurements without boots on was to have information that could be used to summarize the sample for comparison to the overall Army population based on the 1988 US Army Anthropometric Survey (ANSUR 1988).

The majority of the testing took place at stations. All measurements were taken in each configuration¹. The participants were asked to perform each movement three times. From these three measurements, a mean was calculated, and that number was used for analysis.

Each measurement station had one test measurer, and the goniometer and reach stations had data recorders as well. The data recorder's job, beyond recording the measurements on the data sheet and the comments and ratings made by the test participant, was to observe the measurement being taken and ensure that it was being done properly. In essence, the data recorder acted as a second set of eyes for the measurer. All test personnel were trained in all measurements, to act as back-up testers if needed; however, test personnel were able to stay at their assigned stations. At the goniometer and reach stations, personnel performing the data recording and measurer duties took turns acting as measurer and recorder in an effort to ward off tester fatigue.

In an effort to reduce the effects of test participants limbering after they performed the movement repeatedly or tightening up after not moving while waiting for a turn, they were asked to stretch out before each movement. Additionally, if one of the measurements was drastically different from the others or if it appeared that a participant was still stretching out the muscles, a fourth reading/movement was made, and the closest three measurements were used. Because the margins of error for these measurements were not known, measurers and data collectors used their best judgment to determine if another measurement should be taken. If goniometer

¹ Because a limited amount of time was available with the subjects, some subjects did not complete all armor configurations or some portion of stations for a particular armor. Ideally, all subjects would have completed all configurations.

measurements were greater than 10 degrees different, an additional measurement was taken. For reach movements measured in mm, there was more variability between movements, and therefore the variability between measurements could be 35 mm. For the five steps forward movement there was even greater variability (due to the nature of the task), and measurements could vary by as much as 1000 mm.

At the fit, size, and anthropometry station, the following measurements were taken (in addition to the subject being fit into their best body armor size for that configuration):

- Standing Stature (with footwear)
- Seated Stature

At the goniometer station, the following measurements were taken:

- Upper Arm/Shoulder Abduction
- Upper Arm/Shoulder Forward Extension
- Upper Arm/Shoulder Backward Extension
- Upper Leg/Hip Flexion
- Cervical Rotation
- Upper Arm/Shoulder Cross Body Extension (while seated)
- Thoracic/Lumbar Spine Rotation
- Ventral-Dorsal Cervical Flexion

At the reach station, the following measurements were taken:

- Thoracic/Lumbar Spine Lateral Flexion
- Trunk Flexion - Standing
- Trunk Flexion - Seated
- Overhead Fingertip Reach
- Forward Extended Reach
- Cross Body Reach
- High Knee/Knee Lift

At the mission movement station, the following measurement was taken:

- Forward Five Steps

The remaining movements did not have any objective measurements associated with them. Instead, restriction/interference ratings were gathered. Additionally, test participants were asked very specific questions regarding the interference and restriction caused by the body armor. Testers observed these movements and queried the participant about any difficulties they observed. No data for these subjective responses are included in this document because these questions were only asked in configurations where the test participants wore body armor (i.e., not BAPL 0); however, it was still important to document the methodology used. These movements were:

- Stand – Prone – Stand
- Jog
- Take a Knee
- Box Lift

- Target Acquisition
 - Stand with M4
 - Kneel with M4
 - Prone with M4
 - Stand with 9mm

After the participants completed one configuration, they returned to the fit, size, and anthropometry station to receive their next configuration. For each test configuration worn, a data sheet (Appendix A) was completed at each measurement station to record test participant scores, ratings, and comments.

Measurement scores, ratings and comments were entered into computers and tabulated using Microsoft Excel 2007. The Statistical Package for the Social Sciences (SPSS) 18 and Excel were both used to perform data reduction and analyses on the response data. SPSS and Microsoft Excel were used to create table and chart summaries of the results. Excel was used to calculate percentiles.

Personal information on the test participants has been held in the strictest confidence. To ensure the test participants' anonymity and privacy, personal identifiers (e.g., name, social security number, etc.) were not included with any data form, database, or printed results.

2.4 Test Participants

A total of 115 participants were tested in three distinct blocks: first, 72 active duty Army personnel; second, 21 Army reservists; and third, 22 Air Force security personnel (who perform a mission similar to Army military police and infantry). Thus, 93 (or 81%) of them were part of the Army and 22 (19%) were Air Force.

Baseline (BAPL 0, no armor) measurements were taken on each of the 115 test participants. As shown in Table 2, 101 of them were also measured when wearing at least one of the body armor systems, 67 when wearing all three body armor configurations, 70 when wearing BAPL 1, 69 when wearing BAPL 3, and 99 when wearing BAPL 5. Only the Army active duty (Block 1) participants were measured when wearing BAPLs 1 or 3. In some cases, due to time restrictions, test participants only completed a subsection of the movements for a particular configuration or were unable to perform any of the movements in a configuration.

Table 2: Armor configurations worn by participants and measured

	BAPL 0: Baseline	BAPL 0 only	BAPLs 0 & 1*	BAPLs 0 & 3*	BAPLs 0 & 5*	BAPLs 0, 1, 3, & 5
Army Active	72	-	70	69	81	67
Army Reservist	21	4	-	-	6	-
Air Force	22	10	-	-	12	-
Did Not Respond	-	2	-	-	-	-
Total	115	16	70	69	99	67

* Some of these participants also wore other armor systems.

Participants were requested from a variety of demographic backgrounds, including a variety of ages, both genders, all ranks (enlisted personnel, Officers, and Warrant Officers), and aviation, mounted, and dismounted duties. The test participants ranged in age from 19 to 53 ($\bar{x}=27.6$ years, $SD=6.52$). Most (105) of the participants were male (10 female). The majority of participants (89, or 77%) were enlisted personnel (E3-E9), 12 (approximately 10%) were Officers (O1-O4), and 14 (12%) were Warrant Officers (W1-W6). Nearly two-thirds (59) of the 89 enlisted personnel were E4 or E5 (30 and 29, respectively). The majority (7) of the 10 Officers were O2s. The majority (8) of the 12 Warrant Officers were W2s. Of all 115 participants, 51 described their job and mission duties as dismounted, 23 as mounted, 19 as aviation, and 29 as other. Note that Soldiers were allowed to select multiple descriptions; most of the multiple selections were mounted and dismounted.

The participants had up to 28 years of service in the military ($\bar{x}=6.1$ years, $SD=4.94$). There was a wide variety of experience in combat tours, although most had served one tour (46 or 40%); only 18 (16%) had not served a combat tour (Table 3).

Table 3: Combat experience of participants: number of tours served (n=115)

	Combat Tours Served					
	0	1	2	3	4	5
Count	18	46	22	20	8	1
Percent	16%	40%	19%	17%	7%	1%

The participants were also asked about what types of body armor they had experience wearing. Almost all (96, or 83%) stated they had worn the OTV, which has been replaced by the IOTV, but is still in use for training at many locations. Sixty-six participants (57%) had worn the IOTV, 47 (41%) the SPCS, and 13 (11%, but 58% of aviation personnel) the Air Warrior armor system, which is only used by aviation personnel in the Army. Other armor systems that the participants had experience with included the Modular Tactical Vest (MTV), used by the US Marine Corps (5, or 4%), Concealable Body Armor (CBA) (5, or 4%), and the Combat Vehicle Crewman Modular Body Armor System (MBAS) (1, or 1%). Some test participants had also worn off the shelf commercial body armor systems. Only 5 participants (4%) had not worn any plates with their body armor. Almost all of them, 112 (97%), had worn the front plate, and almost as many, 109 (95%), had worn the back plate. A lesser majority, 74 (64%), had worn the side plates. It should be noted that pilots only wear front plates (no back or side plates).

The test participants varied widely in size. During the first data collection phase of the study, only chest circumference measurements were taken on the participants, and armor size was not collected. For the second phase of the study, both chest circumference measurements and stature measurements (without boots) were taken. The measurements were taken in accordance with the 1988 ANSUR measurer's Handbook (Clauser et al. 1988), by a trained anthropometrist. The sample sizes and measurement statistics are listed by armor size in Table 4.

Table 4: Sample size (n) and participant anthropometric size by armor size worn

Body Armor Size	Chest Circumference (mm)					Stature (mm)				
	n	Mean	SD	Min	Max	n	Mean	SD	Min	Max
Extra Small	7	924.1	39.40	885.0	995.0	7	1714.9	57.10	1633.0	1768.0
Small	22	991.7	37.94	926.0	1070.0	22	1748.6	67.70	1625.0	1857.0
Medium	21	1057.5	31.37	1006.0	1109.0	20	1743.0	54.80	1670.0	1856.0
Large	14	1139.6	32.93	1085.0	1212.0	14	1791.1	79.77	1669.0	1916.0
Extra Large	2	1181.0	28.28	1161.0	1201.0	2	1814.0	72.13	1763.0	1865.0
Different Size Systems*	4	979.5	75.00	905.0	1069.0	4	1729.0	63.66	1672.0	1819.0
Unknown	43	1032.3	92.24	815.0	1227.0	-	-	-	-	-
Missing Data	2	-	-	-	-	6	-	-	-	-
Overall	115	1036.6	83.88	815.0	1227.0	75	1752.4	67.78	1625.0	1916.0

* In most cases, the test participants wore the same size armor system for all configurations; however, in four cases, they wore different sized armor for one of the configurations.

For the total sample of those who participated in this evaluation, chest circumferences ranged from 815 mm (approximately 5th percentile for females when compared to the 1988 ANSUR data (Clauser et al. 1988)) to 1,227 mm (between 95th and 97th percentile for males (Clauser et al. 1988)) ($\bar{x}=1,036.6$ mm, SD=83.88). Stature ranged from 1,625 mm (between 45th and 50th percentile for females, but between 2nd and 3rd percentile for males (Clauser et al. 1988)) to 1,916 mm (beyond the 99th percentile for males (Clauser et al. 1988)) ($\bar{x}=1,752.4$ mm, SD=67.78).

Figure 19 shows the data for participants who had both measurements taken. The red lines indicate the approximate location of the 5th percentile female values, and the green lines represent the approximate position of the 95th percentile male values (Clauser et al. 1988). In general, the test sample was tall in terms of stature and large in chest circumference. The large number of participants whose chest circumferences were over the 95th percentile male is likely due to the change in the Army population. The ANSUR II pilot data suggest similar trends (Paquette, Gordon, and Bradtmiller 2009).

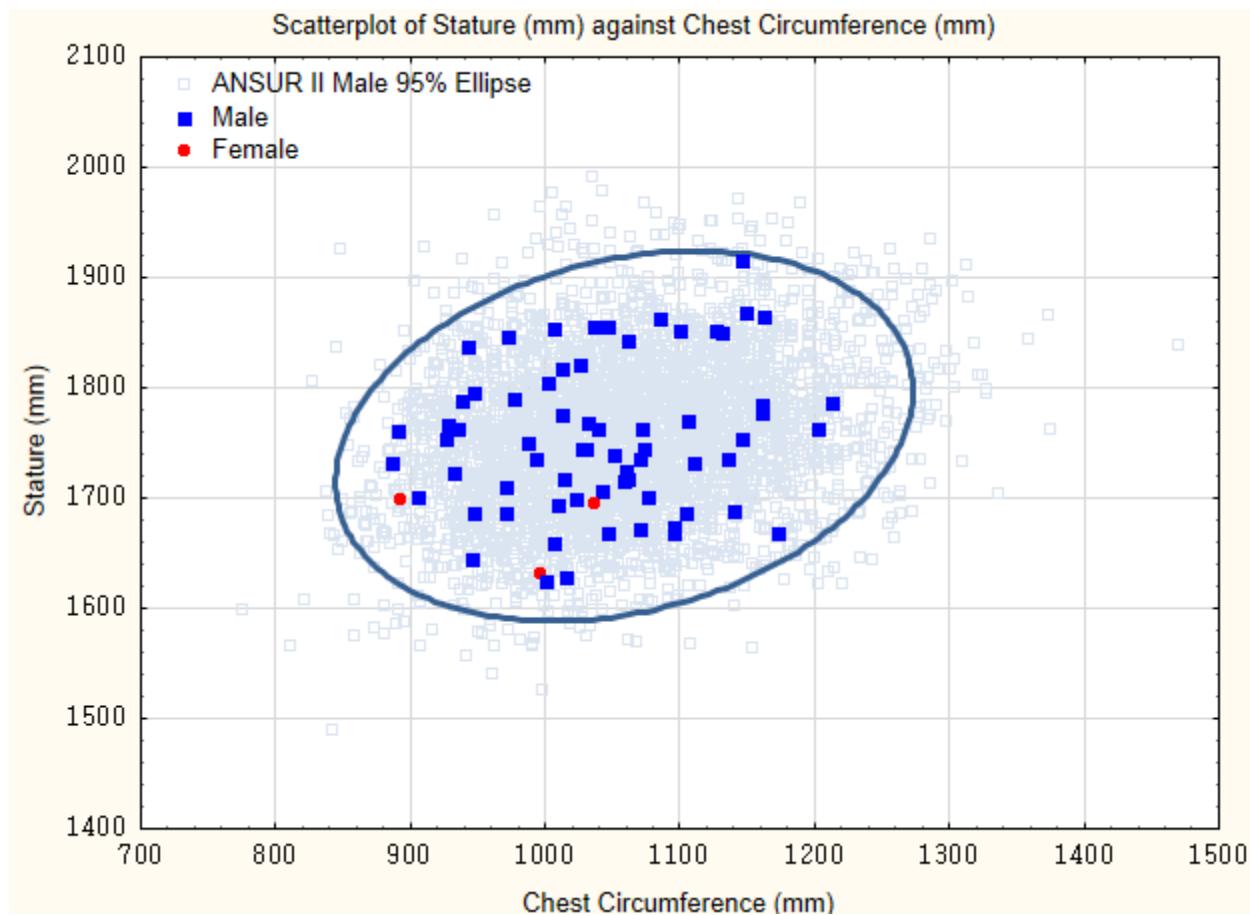


Figure 19: Scatter plot of chest circumferences by stature for test sample compared to those of ANSUR II study with 95% ellipse (males only) (Gordon et al, 2013)

Test participants (in conjunction with the anthropometrist) rated the fit of the body armor on a 1-to-5 scale (1=Very Poor, 2=Poor, 3=Neutral, 4=Good, and 5=Very Good). Table 5 shows the number of participants who wore each size of each body armor configuration and the mean fit rating (and standard deviation), by size and overall, for each size of each configuration. Note that this information was not collected for the first two groups of test participants, so the total sum (n) is much lower than 115. Table 6 lists the number of participants who selected each fit rating for each configuration.

Table 5: Sample size (n) and mean fit rating for each armor configuration by size

Armor	Statistic	Armor Size Worn					Overall
		Extra Small	Small	Medium	Large	Extra Large	
BAPL 1	N	8	23	20	13	2	66
	Mean	4.38	4.00	4.15	3.69	4.00	4.03
	SD	0.74	0.60	0.81	0.95	0.00	0.76
BAPL 3	N	7	24	17	14	2	64
	Mean	3.57	3.63	4.24	4.07	5.00	3.92
	SD	1.13	0.77	0.97	0.73	0.00	0.90
BAPL 5	N	8	22	20	11	2	63
	Mean	3.88	3.77	3.90	3.27	3.50	3.73
	SD	0.35	0.69	0.79	0.79	0.71	0.72

Rating Scale: 1=Very Poor, 2=Poor, 3=Neutral, 4=Good, 5=Very Good

Table 6: Frequency count by fit rating for each armor configuration

Armor	Fit Rating Count				
	1	2	3	4	5
BAPL 1	-	4	6	40	16
BAPL 3	-	6	10	31	17
BAPL 5	-	4	15	38	6

Rating Scale: 1=Very Poor, 2=Poor, 3=Neutral, 4=Good, 5=Very Good

While some test participants received a “Poor” fit in the different body armor configurations, it should be noted that these were the best available fitting sizes, and all were deemed to be an acceptable (although not ideal) fit.

3. ROM PRINCIPLES

This chapter describes the concepts and terminology applicable to the various movements that were assessed during this evaluation (described in detail in Chapter 4) and the postures used as the baseline and starting point for those movements.

3.1 Concepts and Terminology

ROM of body joints is measured using goniometry. The ROM, or maximum angular deviation at the joint, is a means to express joint mobility. The range of joint motion is generally taken at the angle formed by the long axes of two adjoining body segments (such as the femur and tibia). It may also be taken at the angle formed by one body segment and a vertical or horizontal plane. The total ROM is measured between the two extreme positions of the joint. Goniometry is used in medicine and physical therapy as a way to quantitatively measure the performance of different joints which have become degraded (either through age or injury). In test and evaluation of product development, goniometry is used to assess the change in ROM as caused by items being worn on the body, in this case body armor.

Motion is expressed with reference to a particular plane of the body. Definitions of body planes have been established based upon a person being in what is referred to as a standard anatomical position (Figure 20). The position entails a person standing erect, facing forward, and holding his/her arms down at his/her sides with the palms facing forward. Figure 20 includes the planes of the body and anatomical directions referenced to the standard body position and centered on the pelvis. The frontal plane (see plane YZ in Figure 20) divides the front and back (or anterior and posterior) sides of the body. The sagittal plane cuts the body into right and left segments (see plane XZ below). The third plane is the transverse plane, which cuts the body at approximately the waist and divides it into top (superior) and bottom (inferior) segments (plane XY).

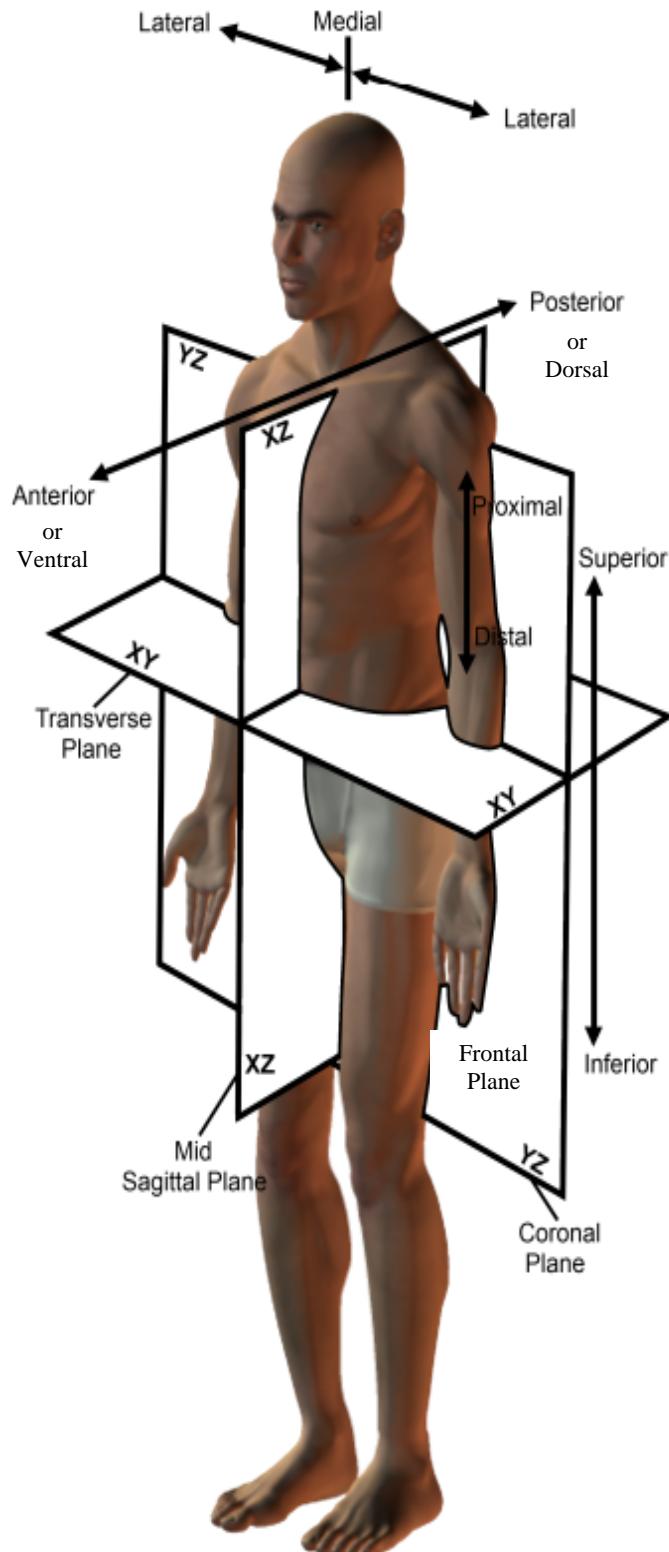


Photo courtesy of Hotzman et al. (2011) *Measurer's Handbook: US Army and Marine Corps Anthropometric Surveys, 2010-2011*. Technical Report (Natick/TR-11/017). U.S. Army Natick Research, Development and Engineering Center, Natick, MA.

Figure 20: Planes of the human body

The direction or plane of motion of a body segment affects the definition of the angle at a joint. Commonly used terminology applied to joint movement is illustrated in Figure 21 and includes the following:

- Flexion – Decreasing the angle between the parts of the body, or bending at a joint
- Extension – Increasing the angle between the parts of the body, or straightening at a joint
- Abduction – Movement of a body segment away from the midline of the body or the part of the body to which it is attached
- Adduction – Movement of a body segment toward the midline of the body or the part of the body to which it is attached
- Rotation – Turning toward or away from the midline of the body.

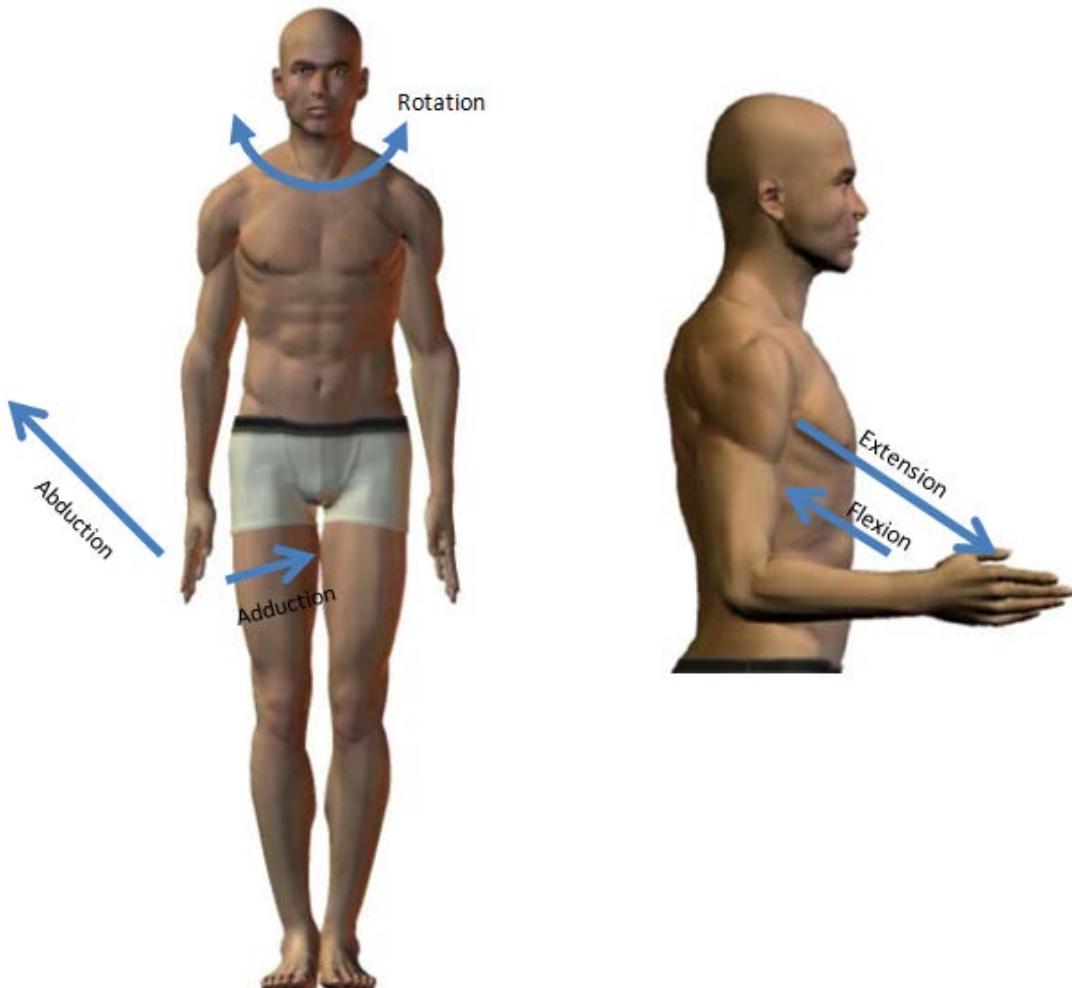


Figure 21: Visual movement descriptions

ROM measurements can be taken in two primary ways: actively and passively. For this evaluation, only active measurements were taken. Active movements are when the participant performs the movement, such as raising an arm. Passive movements are when the tester manipulates the joint, such as raising the arm of the participant, without the participant assisting

the tester in any way. Additionally, a combined method (active assistive) of the two measurements can be taken; both the tester and the participant participate in the movement.

ROM measurements can be affected by numerous different things, including age, gender, body mass index, and left or right side dominance (e.g., right handed). Variables included in the test design and testers can also affect ROM measurements. These included occupational and recreational activities, the time of day testing is completed, testing position used, side of the body (left or right) tested, type of instrument used for testing, and tester experience. Efforts were made for this testing to keep as many of these tester design and tester variables as constant as possible. In an attempt to neutralize the effects of the test participant's individual differences and the time of day, order of presentation was randomized. Testing position and type of instrument are outlined in the movements sections of Chapter 4.

3.2 Postures

Two anthropometric postures, standing position and sitting position (Figure 22) were used as a baseline and starting point for all of the movement measurements described in Chapter 4. These postures involved no movements. The proper positioning of the head (in Frankfurt plane) for both postures is shown in Figure 23. Descriptions of both postures follow the figures.

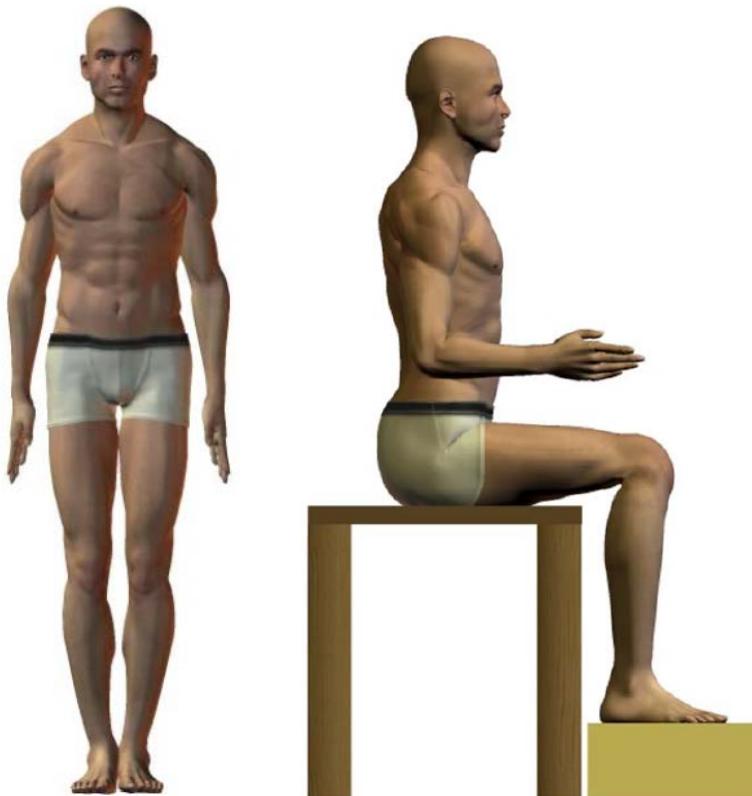


Photo courtesy of Hotzman et al. (2011) *Measurer's Handbook: US Army and Marine Corps Anthropometric Surveys, 2010-2011*. Technical Report (Natick/TR-11/017). U.S. Army Natick Research, Development and Engineering Center, Natick, MA.

Figure 22: Anthropometric standing and seated positions

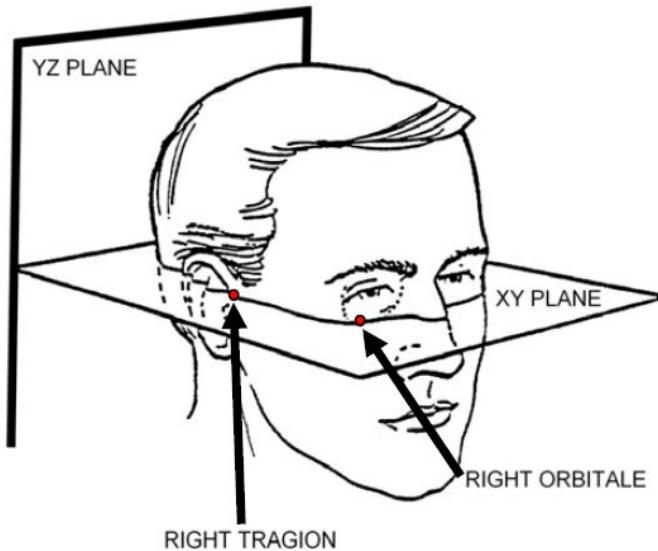


Photo courtesy of Hotzman et al. (2011) *Measurer's Handbook: US Army and Marine Corps Anthropometric Surveys, 2010-2011*. Technical Report (Natick/TR-11/017). U.S. Army Natick Research, Development and Engineering Center, Natick, MA.

Figure 23: Image of head in Frankfurt plane (proper positioning for both standing and seated positions)

ANTHROPOMETRIC STANDING POSITION

Area of Body:	Whole body
Equipment Needed:	None
Movement Sequence:	<ol style="list-style-type: none"> 1. Test participant stands erect. <ol style="list-style-type: none"> a. Weight is evenly distributed on both feet. b. Heels are together. 2. Legs and trunk are straight, but without stiffness. 3. Head is erect, and the participant looks straight ahead, in the Frankfurt plane (Figure 23). 4. Arms are hanging relaxed with elbows lightly touching the sides of the body. <ol style="list-style-type: none"> a. The palms of the hands beside, but not touching, the thighs.

ANTHROPOMETRIC SITTING POSITION

Note: For this position, a chair was used as opposed to the table in the image; chairs allow most participants to be able to sit with their knees at approximately 90°.

Area of Body:	Whole body
Equipment Needed:	Chair without arms
Movement Sequence:	<ol style="list-style-type: none">1. Test participant sits on cushion-less flat surface.<ol style="list-style-type: none">a. Long axes of the thighs are parallel.2. Feet are on an adjustable foot rest (if needed)<ol style="list-style-type: none">a. Knees are flexed at approximately 90°.3. Trunk is erect without stiffness.<ol style="list-style-type: none">a. Joints are NOT locked.4. Head is erect, and the participant looks straight ahead, in the Frankfurt plane (Figure 23).5. Shoulders are relaxed.6. Upper arms are hanging loosely at the sides straight down or with elbows flexed 90° and hands straight; palms face each other.

4. MOVEMENTS AND MEASUREMENT DATA

Measurements were taken for two categories of movement: controlled (Section 4.1) and natural (Section 4.2). Controlled movements have rigorous methods for how an individual should be positioned. A controlled movement is not naturally done during normal activities as it included movement in only one plane. Performing the movement in this fashion allows the isolation of the effects of the ensemble on that one dedicated motion, without allowing the participant to develop a work around. A natural movement allows the participants to complete the movement in task by moving in whatever manner they prefer and is more representative of a real world movement.

A total of 26 movements are presented. Each movement contains a description that includes the following information:

- *Area of Body* (area of focus that can be used to determine if it is a relevant measure for a certain piece of personal protective equipment, e.g., head or neck movement is relevant to helmets)
- *Plane* (controlled movements only)
- *Equipment Needed*
- *Movement Sequence*
- *Measurement Sequence*
- *Cautions*
- *Potential Causes of Restriction*
- *Real World Equivalent* (for controlled movements, military movements that include the described movement, although in a less controlled manner) (for natural movements, controlled movements that are components of the described movement, to include a series of pass/fail or yes/no questions if no objective measurement is included)
- *Controlled Movement Components* (natural movements only)
- *Pass/Fail Criteria* (as needed)
- *Data Collection* (how the measurement data are set up on a collection sheet and any manipulation that needs to be done to the data, e.g., subtracting the thickness of the body armor system)
- *Reminder* (as needed)

This set of information is followed by a figure (Figures 24-49), containing at least one image that illustrates how the movement is conducted and measured.

Each movement that has objective measurements also contains a Summary Statistics section (following the figure) that consists of two tables of data (Tables 7-42) for the baseline configuration (BAPL 0, ACU). The table on the left for each movement gives the number of test participants (n), the mean, minimum, and maximum scores, the standard deviation (SD), and the skewness and the skew's standard deviation (skew SD) in parentheses. The standard deviation and skewness show how normal the distribution scale was. The second table for each movement gives percentile rankings for the scores. If a person had a score at the 20th percentile, 20 percent of the population scored lower than him/her.

In some cases, such as the trunk flexion movements, where the lowest score indicates the best performance, these numbers are flipped so that best performance (i.e., the lowest numbers) is in the 99th percentile range and the worst performance (i.e., the highest numbers) is in the 1st percentile range. The 50th percentile, or median, is highlighted in light grey. This table allows readers to see the distribution of data and, when doing their own measurements, see how their participants compare to this sample of participants.

4.1 Controlled Movements

CERVICAL ROTATION – Neck Rotation (Side to Side)

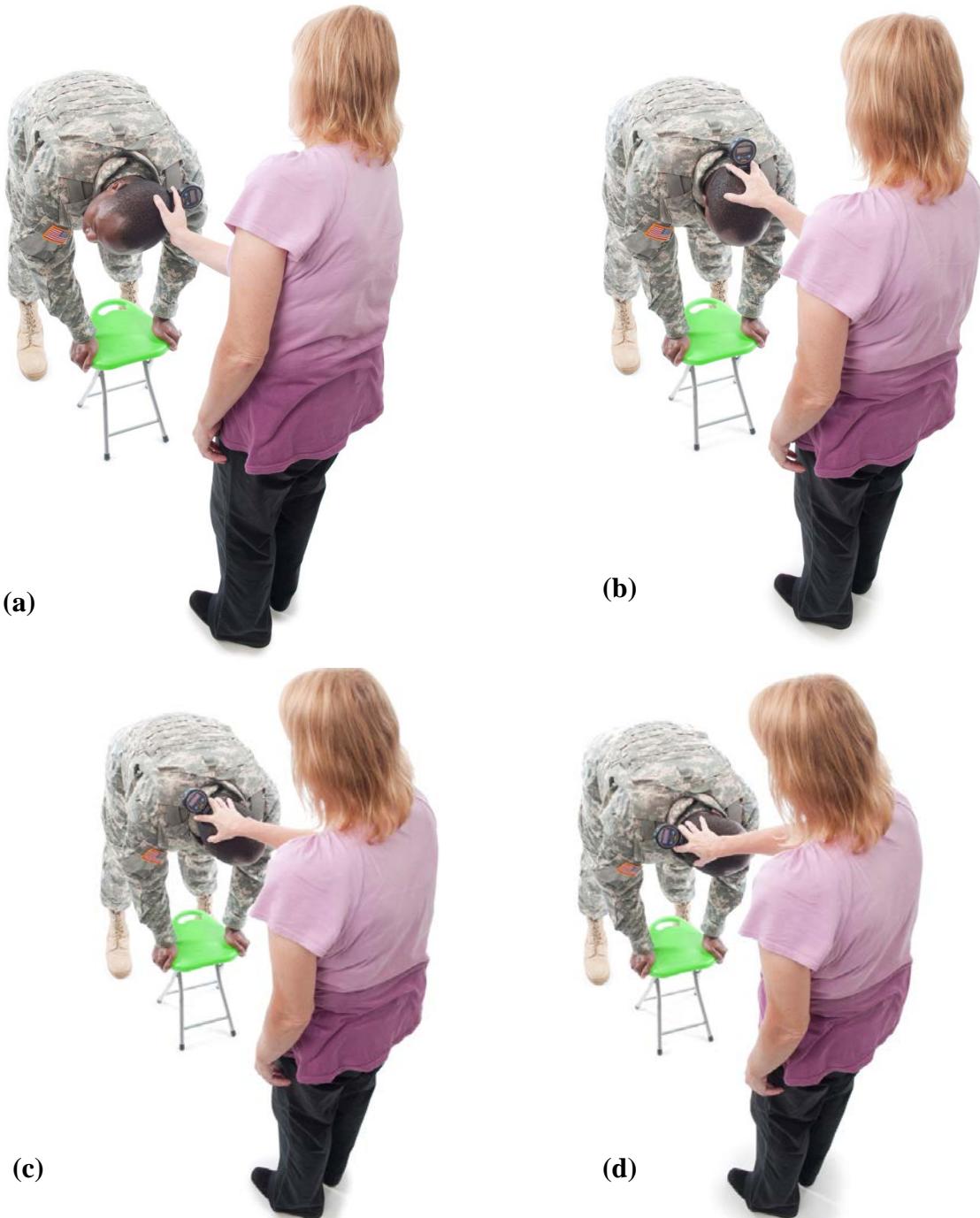
Description

Area of Body:	Neck, Head
Plane:	Transverse
Equipment Needed:	<ul style="list-style-type: none">• Digital inclinometer• Straight-back chair (without arms) or stool
Movement Sequence:	<ol style="list-style-type: none">1. Participant stands facing chair.2. Participant bends forward at the waist.<ol style="list-style-type: none">a. Head and chest should be parallel to the floor, so the spine makes a relatively flat/straight line.b. Test participant grasps the seat of the chair to hold the position.c. Any inclination by the participant to get into a push up or plank position should be discouraged, as it is not necessary and causes strain and fatigue on the arms.3. Participant turns head as far to the right as possible and holds it.4. Participant then turns head as far to the left as possible and holds it while a measurement is taken.
Measurement Sequence:	<ol style="list-style-type: none">1. Participant turns head as far to the right as possible, and the inclinometer is set to “0”.2. The inclinometer is held in place by the tester on the back surface of the head.3. Measurement is taken after the turn has been completed and the participant’s head is as far to the left as possible.4. The inclinometer is held lightly, but firmly, on the participant’s head, to ensure it stays in the same location without causing discomfort for the participant.
Cautions:	<ul style="list-style-type: none">• Ensure that the thoracic and lumbar spine does not twist or rotate.• Ensure that head/neck does not drop down or lift up and stays aligned with the spine.• Ensure no twisting/rotation of hips; they should be locked.

CERVICAL ROTATION

Potential Causes of Restriction:	<ul style="list-style-type: none">• Collar/neck height is tall.• Circumference of the neck/head opening is small.• Vest is long, causing it to ride up into the neck area when participant bends at the waist (i.e., sitting or bending over).• Vest/plate sits higher than the suprasternale. <p>Note: Bending at the waist (needed to ensure the measuring device works properly) may push the vest up higher than it would be in a standing position, although there is a need to turn the head when in all positions.</p>
Real World Equivalents:	<ul style="list-style-type: none">• Turning to look in all directions while operating a vehicle• Standing watch• Crew chief performing hoist operations
Data Collection:	Measurement 1 Measurement 2 Measurement 3 Mean 1-3 There is no manipulation of the data. Three measurements are taken, and a mean is calculated and used as the score.

CERVICAL ROTATION



Note: Images show movement being performed in order of a, b, c, d.

Figure 24: Cervical Rotation

CERVICAL ROTATION

Summary Statistics

Table 7: Cervical Rotation, measured in degrees

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
N	111	68	67	95
Mean	155.7	125.1	151.1	126.7
Degradation of Mean	-	19.7%	3.0%	18.6%
Min	127.7	38.0	115.7	29.0
Max	178.0	166.3	182.0	169.0
SD	12.17	23.1	13.9	18.9
Skewness (Skew SD)	-0.004 (0.229)	-1.109 (0.291)	-0.029 (0.293)	-1.309 (0.247)

*Mean, Min, Max, and SD data in degrees,

CERVICAL ROTATION

Table 8: Percentiles for Cervical Rotation scores

Percentile	Degrees			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	132.2	63.0	119.4	65.0
2 nd	134.0	74.8	122.3	67.7
3 rd	135.4	75.3	124.2	75.3
5 th	137.0	83.2	128.5	84.6
10 th	141.0	95.0	135.7	100.7
15 th	142.5	104.1	137.9	106.2
20 th	144.3	110.6	139.5	115.2
25 th	145.2	114.7	142.9	116.9
30 th	147.3	117.8	144.9	120.0
35 th	149.3	121.9	145.7	123.6
40 th	153.0	123.1	148.2	124.9
45 th	155.0	128.7	150.7	125.8
50 th	155.7	130.7	151.0	128.7
55 th	156.9	132.1	152.0	131.7
60 th	158.0	133.0	152.4	133.3
65 th	160.9	135.6	154.8	134.8
70 th	163.3	137.7	156.9	138.9
75 th	165.4	139.3	158.3	141.4
80 th	167.7	142.1	160.3	144.0
85 th	170.5	143.3	168.0	145.9
90 th	173.3	151.1	171.6	151.9
95 th	174.9	154.5	173.6	154.7
97 th	175.6	159.8	174.1	156.5
98 th	175.9	160.8	176.7	160.0
99 th	177.8	162.9	179.4	167.1

VENTRAL-DORSAL CERVICAL FLEXION – Neck Extension (Chin to chest)

Description

Area of Body:	Neck, Head
Plane:	Sagittal
Equipment Needed:	<ul style="list-style-type: none"> • Digital inclinometer • Straight-back chair
Movement Sequence:	<ol style="list-style-type: none"> 1. Test participant sits upright in a chair with his/her hands clasped behind the back of the chair <ol style="list-style-type: none"> a. Chest and shoulders should not move b. Legs should be at approximately 90° with the test participant's feet flat on the floor 2. Participant moves head as far forward (chin against the chest, collar, etc.) as possible, without reaching their neck forward. 3. Participant moves head as far back as possible, until any restriction is reached or the head has moved as far as the test participant can move it
Measurement Sequence:	<ol style="list-style-type: none"> 1. The inclinometer is mounted/held on the top of the head (cranial surface). 2. “0” the inclinometer when test participant’s head is forward and down in a ventral position 3. Measurement is taken when the test participant has raised their head and looked up/back as much as possible
Cautions:	<ul style="list-style-type: none"> • Participant’s trunk and shoulders should be kept straight. • Participant should clasp hands behind the chair. • Participant should not roll or arch the thoracic area or shoulders. • Participant’s neck should stay in plane and should not move forward and backward (i.e., reaching).
Potential Causes of Restriction:	<ul style="list-style-type: none"> • Collar/neck height is tall. • Circumference of the neck/head opening is small. • Length of vest is long, causing the vest to ride up into the neck area when participant bends at the waist. • Vest/plate sits higher than the suprasternale. <p>Note: Sitting may push the vest up higher than it would be in a standing position, although there is a need to turn the head when in all positions.</p>

VENTRAL-DORSAL CERVICAL FLEXION

Real World Equivalents:	<ul style="list-style-type: none"> • Looking down/up • Scanning the area while on guard duty 			
Data Collection:	Measurement 1	Measurement 2	Measurement 3	Mean 1-3

There is no manipulation of the data. Three measurements are taken, and a mean is calculated and used as the score.



Figure 25: Ventral-Dorsal Cervical Flexion

Summary Statistics

Table 9: Ventral-Dorsal Cervical Flexion, measured in degrees

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
N	111	68	67	95
Mean	118.7	94.7	113.0	94.5
Degradation of Mean	-	20.2%	4.8%	20.4%
Min	86.0	35.3	81.3	45.7
Max	162.0	138.7	151.0	141.3
SD	16.2	18.7	15.5	18.6
Skewness (Skew SD)	0.32 (0.23°)	-0.33° (0.29)	-0.01 (0.29)	-0.31 (0.25)

*Mean, Min, Max, and SD data in degrees

VENTRAL-DORSAL CERVICAL FLEXION

Table 10: Percentiles for Ventral-Dorsal Cervical Flexion scores

Percentile	Degrees			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	87.7	52.8	81.8	48.5
2 nd	88.5	62.2	82.6	51.6
3 rd	91.0	64.4	84.0	52.2
5 th	93.2	65.9	85.3	61.3
10 th	99.3	70.5	95.1	72.6
15 th	101.5	75.1	96.2	78.1
20 th	104.7	79.6	100.8	82.9
25 th	106.5	82.7	103.0	85.5
30 th	109.3	86.2	104.2	86.8
35 th	111.9	90.6	107.4	88.7
40 th	113.7	92.0	109.1	89.5
45 th	115.8	94.1	111.8	91.2
50 th	118.0	96.3	113.3	93.7
55 th	120.0	99.1	114.7	96.2
60 th	122.0	100.9	118.1	98.9
65 th	125.0	102.0	119.3	100.9
70 th	127.0	103.9	120.8	104.2
75 th	129.2	104.7	123.2	106.8
80 th	130.7	108.9	125.6	112.3
85 th	134.8	113.4	128.7	115.7
90 th	139.3	116.5	132.3	117.7
95 th	146.9	124.5	135.8	119.3
97 th	153.4	126.0	141.1	122.7
98 th	154.5	127.1	143.0	126.6
99 th	157.0	131.2	146.4	131.9

THORACIC/LUMBAR SPINE ROTATION

Description

Area of Body:	Torso
Plane:	Transverse
Equipment Needed:	<ul style="list-style-type: none"> • Protractor goniometer • Chair (without arms or back) or small stool • Step stool for tester to stand on (optional) • A second test person (i.e., a data recorder) to help line up this measurement accurately (optional) • Sticker or piece of tape to mark test participants' approximate location of the acromion and a central point on the head (optional)
Movement Sequence:	<ol style="list-style-type: none"> 1. Participant is in sitting posture in chair that has no arms or back. <ol style="list-style-type: none"> a. Arms are crossed against the chest. b. Shoulders are back and set. c. Feet are flat on the floor, approximately shoulder width apart, with knees at approximately 90°. d. Participant sits upright. 2. Participant turns/twists at the lower back as far to the right as possible and holds it. <ol style="list-style-type: none"> a. Head follows the chest so that participant always looks straight ahead and in the direction the chest is facing. 3. Participant rotates as far to the left as possible and holds the position. 4. Movement should be performed two to three times before the measurements are started to ensure that the participant is limber.
Measurement Sequence:	<ol style="list-style-type: none"> 1. Center joint of goniometer should be over the participant's head, but not at the center of the head, and should be above the location where the spine would be if it radiated upward. (Sticker can be used to mark this location and make tracking this easier.) 2. Sticker or other mark should be placed approximately at participant's acromion. (See Hotzman et al. 2011 or Gordon et al. 1989 for a description.)

THORACIC/LUMBAR SPINE ROTATION

	<p>3. When participant turns to the maximum position (right), measurer places the arm of the goniometer over the shoulder (at approximately the acromion).</p> <ol style="list-style-type: none"> a. Assistance will likely be needed from the data recorder to aid and confirm that arm of goniometer is lined up appropriately. b. The arm of the goniometer should form a line between the sticker dot on the participant's head and the sticker dot on the shoulder. c. Measurer must ensure that this arm of the goniometer does not move as the participant rotates and the measurer moves the second arm of the goniometer. <p>4. When participant turns to the left, reaches maximum rotation, and holds the position, the second arm of the goniometer should follow/align with the shoulder mark.</p> <ol style="list-style-type: none"> a. The data recorder ensures that the second arm of the goniometer is lined up along the dot on the shoulder at the conclusion of this movement. b. Measurement is taken.
<i>Cautions:</i>	<ul style="list-style-type: none"> • Ensure that participant does not turn/twist knees, hips, upper back, or head. • Ensure that participant does not slide on seat as he/she turns.
<i>Potential Causes of Restriction:</i>	<ul style="list-style-type: none"> • Circumference of the vest in the chest and the stomach is small or does not have enough adjustability. • Vest is long.
<i>Real World Equivalents:</i>	<ul style="list-style-type: none"> • Turning to operate controls while seated • Turning to look in all directions
<i>Data Collection:</i>	<p>Measurement 1 Measurement 2 Measurement 3 Mean 1-3</p> <p>There is no manipulation of the data. Three measurements are taken, and a mean is calculated and used as the score.</p>

THORACIC/LUMBAR SPINE ROTATION

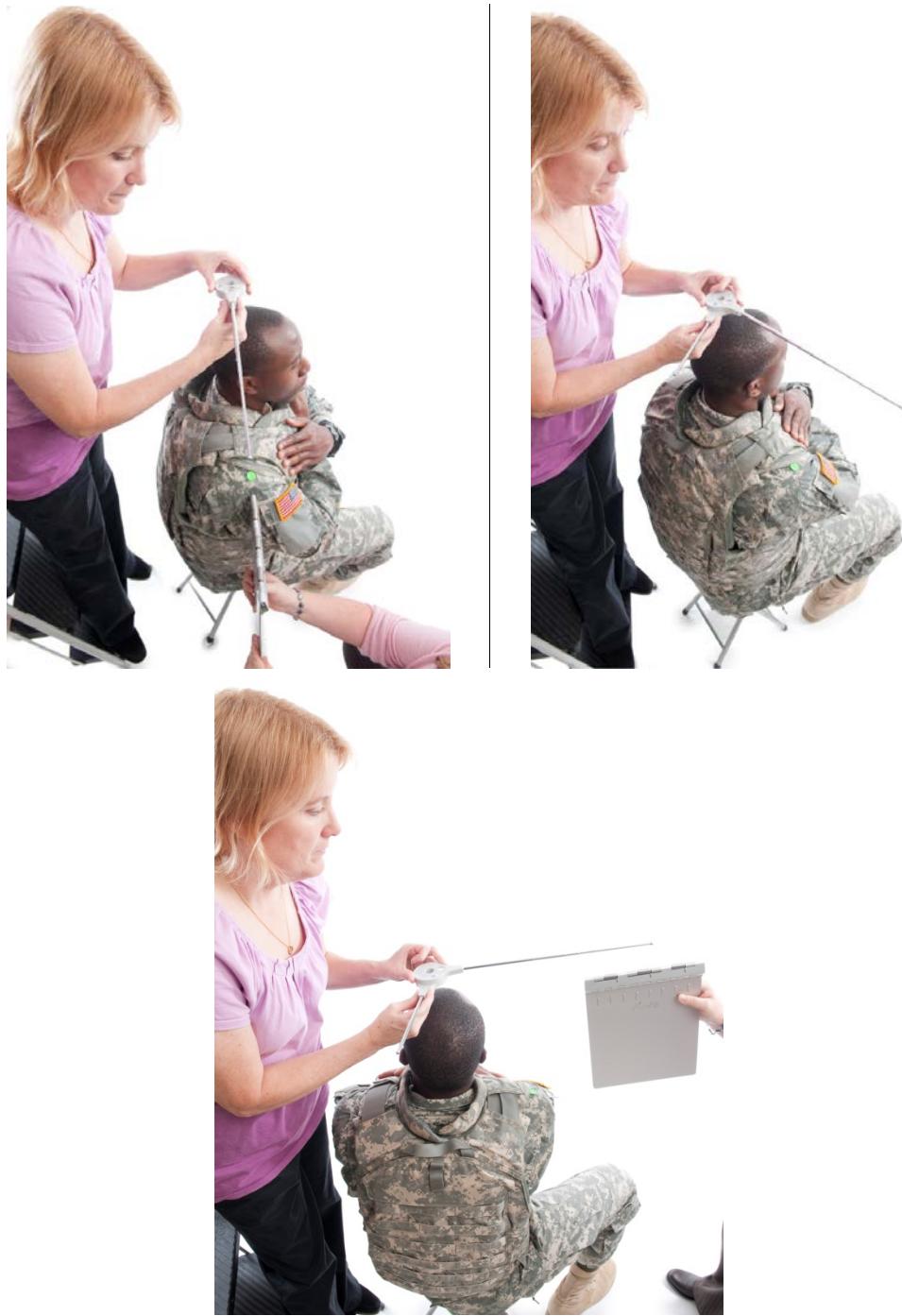


Figure 26: Thoracic/Lumbar Spine Rotation

THORACIC/LUMBAR SPINE ROTATION

Summary Statistics

Table 11: Thoracic/Lumbar Spine Rotation, measured in degrees

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
N	111	68	67	95
Mean	105.1	86.6	89.4	84.3
Degradation of Mean	-	17.6%	14.9%	19.8%
Min	71.3	50.7	50.0	39.7
Max	173.3	152.0	154.7	134.3
SD	19.4	19.9	19.4	19.8
Skewness (Skew SD)	0.71 (0.23)	1.14 (0.29)	1.03 (0.29)	0.10 (0.25)

*Mean, Min, Max, and SD data in degrees

THORACIC/LUMBAR SPINE ROTATION

Table 12: Percentiles for Thoracic/ Lumbar Spine Rotation scores

Percentile	Degrees			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	71.8	53.8	55.3	42.8
2 nd	73.2	55.8	59.0	48.9
3 rd	75.1	56.8	60.9	52.7
5 th	77.8	59.7	64.2	54.6
10 th	81.7	66.6	69.0	59.3
15 th	84.2	68.4	74.6	62.1
20 th	87.7	72.1	75.1	65.8
25 th	91.7	73.7	77.4	69.9
30 th	93.7	76.5	79.3	73.1
35 th	95.9	79.6	80.8	76.5
40 th	99.3	80.8	81.8	78.9
45 th	101.9	82.3	83.3	81.2
50 th	104.0	83.0	85.0	84.0
55 th	105.2	86.6	87.3	86.2
60 th	108.3	88.2	90.4	90.1
65 th	110.0	89.3	93.6	92.0
70 th	113.3	91.3	95.6	94.6
75 th	115.0	94.7	98.9	97.0
80 th	119.0	97.5	102.5	100.6
85 th	125.7	101.1	104.4	105.2
90 th	130.7	107.2	111.8	112.1
95 th	137.9	132.0	126.0	115.6
97 th	142.1	137.9	135.1	118.8
98 th	142.6	138.2	139.8	121.2
99 th	162.8	142.7	146.3	123.4

THORACIC/LUMBAR SPINE LATERAL FLEXION

Description

Area of Body:	Whole body, torso
Plane:	Frontal
Equipment Needed:	<ul style="list-style-type: none"> • Anthropometer • Wall to stand against
Movement Sequence:	<ol style="list-style-type: none"> 1. Test participant should remove all items from pockets. 2. Participant stands with feet a shoulder width apart in the anthropometric standing posture. <ol style="list-style-type: none"> a. Back against a wall (lightly touching, but not leaning against) b. Arms hanging freely at the sides of the body with palms facing against thighs 3. Participant bends at waist, leaning as far to the right side of the body as possible, without falling over, while keeping body in the frontal plane. 4. Participant's hand should slide down leg with fingertips pointed toward the ground. 5. Both feet should remain firmly on the ground with weight evenly distributed. 6. Knees should remain straight. 7. Participant should hold maximum position.
Measurement Sequence:	<ol style="list-style-type: none"> 1. With participant in the anthropometric standing posture with hands at side, measurer records height from the floor to the longest fingertip on the right hand, usually the middle finger, <ol style="list-style-type: none"> a. Anthropometer should remain upright and perpendicular to the floor. b. Measurer should ensure that the top of the anthropometer does not hit/restrict the participant. c. If the participant is restricted by the bunching of the trousers or the seams of the pockets, the measurer can flatten out this material to aid the participant. 2. With participant leaning as far to the right as possible, measurer again records the height from the floor to the longest fingertip on the right hand. 3. A delta between the two measurements is calculated during data analysis.

THORACIC/LUMBAR SPINE LATERAL FLEXION

Cautions:	<ul style="list-style-type: none"> • Participant should not lean forward or backward. • Participant's hand should follow the leg so that participant does not reach outward with their arm. • Participant should not bend knees or hip. • Participant's fingers should be extended. • Participant should look straight ahead. 												
Potential Causes of Restriction:	<ul style="list-style-type: none"> • Vest is long, covers, and/or catches on hips during movement. • Circumference at the hips is small (although it may be large at the waist/stomach area). 												
Real World Equivalents:	<ul style="list-style-type: none"> • Leaning out a window while in a vehicle • Reaching for objects at the side 												
Data Collection:	<table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 33%;">Standing 1+10 mm</td> <td style="width: 33%;">Reach 1+10 mm</td> <td style="width: 33%;">Delta 1</td> </tr> <tr> <td>Standing 2+10 mm</td> <td>Reach 2+10 mm</td> <td>Delta 2</td> </tr> <tr> <td>Standing 3+10 mm</td> <td>Reach 3+10 mm</td> <td>Delta 3</td> </tr> <tr> <td></td> <td></td> <td>Mean Delta 1-3</td> </tr> </table> <p>This movement requires two measurements. The first is from the starting position (Standing), and the second is when the participant reaches as far as possible (Reach). Both of these measurements have 10 mm (the width of the anthropometer blade/arm) added to them to reflect the accurate height. If the measurement is taken from the tip of the blade, then the 10 mm do not need to be added.</p> <p>For each set of measurements, a delta should be calculated, subtracting the encumbered measurement from the baseline (BAPL 0) measurement.</p> <p>A mean is calculated using the three deltas derived. That mean is used as the score.</p> <p>Note: The height of the reach measurement (Reach 1-3+10 mm) can also be used alone as an alternate variable.</p>	Standing 1+10 mm	Reach 1+10 mm	Delta 1	Standing 2+10 mm	Reach 2+10 mm	Delta 2	Standing 3+10 mm	Reach 3+10 mm	Delta 3			Mean Delta 1-3
Standing 1+10 mm	Reach 1+10 mm	Delta 1											
Standing 2+10 mm	Reach 2+10 mm	Delta 2											
Standing 3+10 mm	Reach 3+10 mm	Delta 3											
		Mean Delta 1-3											

THORACIC/LUMBAR SPINE LATERAL FLEXION



Figure 27: Thoracic/Lumbar Spine Lateral Flexion

Summary Statistics

Table 13 Thoracic/Lumbar Spine Lateral Flexion, measured in mm

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
N	112	67	67	95
Mean	214.2	187.6	193.0	171.6
Degradation of Mean	214.2	187.6	193.0	171.6
Min	115.0	12.7	101.0	73.0
Max	311.7	315.3	348.3	286.3
SD	43.0	47.8	43.7	39.8
Skewness (Skew SD)	0.00 (0.23)	-0.21 (0.29)	0.71 (0.29)	0.36 (0.25)

*Mean, Min, Max, and SD data in mm

THORACIC/LUMBAR SPINE LATERAL FLEXION

Table 14: Percentiles for Thoracic/Lumbar Spine Lateral Flexion scores

Percentile	mm			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	116.0	82.8	113.1	98.1
2 nd	124.8	118.3	122.0	108.5
3 rd	130.4	120.3	127.5	110.5
5 th	142.3	126.6	135.0	116.3
10 th	159.3	135.4	141.9	124.6
15 th	171.9	143.7	146.8	131.8
20 th	180.6	148.7	157.8	138.2
25 th	186.6	161.4	164.2	139.2
30 th	191.2	166.8	169.8	143.9
35 th	199.3	176.3	174.2	151.9
40 th	204.5	179.9	177.9	155.9
45 th	210.2	181.8	181.7	164.4
50 th	213.5	185.9	185.3	169.7
55 th	221.3	189.6	196.3	175.5
60 th	224.2	193.6	201.2	184.5
65 th	229.8	200.2	209.0	188.4
70 th	234.5	208.0	215.1	193.2
75 th	239.1	215.3	220.4	198.0
80 th	247.2	217.2	227.9	203.4
85 th	259.1	228.6	231.3	208.9
90 th	274.6	253.0	243.1	219.3
95 th	284.3	267.1	263.3	238.6
97 th	298.0	275.9	273.3	242.6
98 th	307.3	277.5	284.8	252.9
99 th	310.2	290.5	310.0	284.1

SHOULDER ABDUCTION

Description

Area of Body:	Shoulder, arms, torso
Plane:	Frontal
Equipment Needed:	<ul style="list-style-type: none"> • Digital inclinometer, with attachable ruler • Doorway, cabinet, or other corner
Movement Sequence:	<ol style="list-style-type: none"> 1. Test participant stands facing the outside edge of a door frame with outermost point (i.e., chest, toes) lightly touching the flat surface of the door frame or cabinet*. <ol style="list-style-type: none"> a. Arms should hang at side, with palms facing in toward body. b. Participant should not be leaning against the wall or using it for support. 2. Participant raises <u>both</u>** arms sideward and upward as far as possible while in a standing position. <ol style="list-style-type: none"> a. Arms should follow the frontal plane of the body. b. Elbow and wrist should stay straight. <p>* Due to the body armor and/or participant's body type, toes, abdomen, sternum, and nose may not all be able to touch wall. Tester must utilize the outermost point and must ensure the participant is in a vertical plane.</p> <p>** If door frame (or other device) does not allow for both arms to be raised, just the right arm can be used, although the measurer should ensure that the participant does not lean toward their left side.</p> <p>Note: This movement can also be conducted with participant seated in a chair without arms, although special care must be taken to ensure there are no extraneous movements. Participant should sit in anthropometric position, with back lightly touching chair back.</p>
Measurement Sequence:	<ol style="list-style-type: none"> 1. Place digital inclinometer on the right arm just above the elbow with the dial on the posterior (back) side of the arm <ol style="list-style-type: none"> a. The ruler portion of the inclinometer should follow the humerus bone to the ball and socket of the shoulder blade (as best as possible) 2. Set inclinometer to "0" when participant's arm is at side. 3. Ensure that ruler follows humerus as test participant moves arms. 4. Ensure that participant's arms are above shoulders (unless he/she has experienced some type of injury), but not behind the head.

SHOULDER ABDUCTION

Cautions:	<ul style="list-style-type: none"> • Ensure no extension of the back. • Ensure no arm rotation. • Ensure no elbow flexion/bend. • Ensure no movement out of the frontal plane.
Potential Causes of Restriction:	<ul style="list-style-type: none"> • Armor chest breadth is wide, and/or front plate is too wide. • Arm hole opening is narrow. • Strap going over the shoulder of the vest is wide.
Real World Equivalents:	<ul style="list-style-type: none"> • Raising arm to perform hand signals in a dismounted movement • Reaching up to operate controls on the ceiling of a vehicle
Data Collection:	Measurement 1 Measurement 2 Measurement 3 Mean 1-3 There is no manipulation of the data. Three measurements are taken, and a mean is calculated and used as the score.



Figure 28: Shoulder Abduction

SHOULDER ABDUCTION

Summary Statistics

Table 15: Shoulder Abduction, measured in degrees

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
N	111	68	67	95
Mean	161.7	134.7	141.5	128.1
Degradation of Mean	-	16.7%	12.5%	20.8%
Min	112.7	84.3	104.7	90.0
Max	182.3	162.0	168.0	154.0
SD	11.0	13.8	14.1	15.2
Skewness (Skew SD)	-1.36 (0.23)	-0.66 (0.29)	-0.44 (0.29)	-0.41 (0.25)

*Mean, Min, Max, and SD data in degrees

SHOULDER ABDUCTION

Table 16: Percentiles for Shoulder Abduction scores

Percentile	Degrees			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	126.3	100.2	107.1	92.8
2 nd	135.1	108.8	108.5	99.4
3 rd	136.1	110.8	109.0	101.1
5 th	143.0	114.1	117.1	102.2
10 th	151.0	118.6	125.3	106.8
15 th	153.4	120.8	129.0	110.3
20 th	155.7	123.9	130.0	112.9
25 th	156.7	127.0	133.2	117.3
30 th	157.7	127.7	134.2	119.0
35 th	159.3	130.4	135.3	123.2
40 th	160.3	133.1	136.9	125.8
45 th	161.3	135.3	138.5	128.2
50 th	162.0	136.7	143.0	130.3
55 th	163.7	138.7	145.4	134.0
60 th	165.3	140.0	146.2	135.6
65 th	166.9	140.7	147.3	136.3
70 th	169.0	141.8	149.4	137.3
75 th	169.9	143.3	153.2	139.7
80 th	171.0	146.1	155.5	140.7
85 th	172.9	147.3	157.3	144.7
90 th	173.3	151.8	158.0	146.8
95 th	175.7	156.6	160.7	149.3
97 th	176.9	157.0	161.8	149.8
98 th	177.2	158.9	164.4	150.4
99 th	177.7	160.6	166.5	153.3

SHOULDER OVERHEAD FINGERTIP REACH, EXTENDED

Description

Area of Body:	Shoulder, arms, torso
Plane:	Frontal
Equipment Needed:	<ul style="list-style-type: none"> • Wall • Wall scale (vertical) • Measuring block • 20 cm block (to place against wall) • Sturdy ladder or step stool for measurer to stand on
Movement Sequence:	<ol style="list-style-type: none"> 1. A 20 cm block should be placed against the wall. 2. Test participant stands facing a wall-mounted scale with both arms extended overhead and parallel to each other. <ol style="list-style-type: none"> a. Tips of toes are 20 cm from the wall (against block). b. Feet are slightly spread, approximately 20 mm apart. 3. Test participant rests palms on the scale over his/her head. <ol style="list-style-type: none"> a. Upper chest rests against the wall. b. Palms are over the participant's shoulders. 4. Elbows are straightened. 5. Participant reaches as high as possible overhead with <u>both</u> hands while sliding palms up the scale as he/she extends and stretches, keeping heels flat on the floor.
Measurement Sequence:	<ol style="list-style-type: none"> 1. When the participant reaches the maximum height possible, the measurer places the bottom edge of the measuring block against the tip of the participant's longest finger (typically the middle finger) with the side of the measuring block against the vertical wall scale. <ol style="list-style-type: none"> a. Ensure that the measuring block is parallel to the floor and not at an angle by utilizing the lines on the wall scale. b. Ensure that participant's hands are at approximately the same height on the wall scale. Any differences greater than 10 cm should be repeated. <p>Note: a stool will likely be needed for the tester to stand on.</p>
Cautions:	<ul style="list-style-type: none"> • Ensure that measuring block is parallel to the floor and not at an angle. • Ensure that participant's heels do not lift off floor.

SHOULDER OVERHEAD FINGERTIP REACH, EXTENDED

Potential Causes of Restriction:	<ul style="list-style-type: none"> • Strap over the shoulder of the vest is wide.
Real World Equivalents:	<ul style="list-style-type: none"> • Reaching to operate overhead controls. • Lifting a box overhead.
Data Collection:	<p>Measurement 1 Measurement 2 Measurement 3 Mean 1-3</p> <p>There is no manipulation of the data. Three measurements are taken, and a mean is calculated and used as the score.</p>



Figure 29: Shoulder Overhead Fingertip Reach, Extended

SHOULDER OVERHEAD FINGERTIP REACH, EXTENDED

Summary Statistics

Table 17: Shoulder Overhead Fingertip Reach, Extended, measured in mm

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
N	113	67	67	95
Mean	2231.3	2197.4	2212.0	2160.7
Degradation of Mean	-	1.5%	0.9%	3.2%
Min	1930.0	2001.7	2010.7	1877.0
Max	2423.3	2393.7	2400.3	2376.3
SD	101.1	93.3	95.7	100.8
Skewness (Skew SD)	-0.35 (0.23)	0.08 (0.29)	0.05 (0.29)	-0.22 (0.24)

* Mean, Min, Max, and SD data in mm

SHOULDER OVERHEAD FINGERTIP REACH, EXTENDED

Table 18: Percentiles for Shoulder Overhead Fingertip Reach, Extended scores

Percentile	mm			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	1978.2	2009.9	2012.9	1901.4
2 nd	2024.5	2020.1	2025.8	1907.1
3 rd	2030.7	2032.1	2050.3	1965.1
5 th	2055.6	2046.3	2086.3	1999.0
10 th	2114.5	2089.6	2096.2	2050.5
15 th	2139.6	2102.1	2113.0	2070.7
20 th	2151.5	2129.3	2120.7	2087.3
25 th	2161.3	2135.1	2139.9	2095.2
30 th	2169.0	2143.2	2144.8	2118.3
35 th	2190.5	2150.3	2158.6	2123.3
40 th	2202.0	2159.4	2173.4	2128.3
45 th	2217.7	2179.5	2184.6	2139.5
50 th	2231.0	2188.7	2195.0	2158.7
55 th	2248.3	2208.2	2227.8	2167.1
60 th	2261.2	2228.5	2247.9	2177.8
65 th	2286.8	2245.6	2257.9	2198.7
70 th	2295.6	2254.8	2274.9	2220.3
75 th	2308.0	2263.6	2284.7	2235.2
80 th	2323.7	2281.9	2290.9	2249.5
85 th	2346.4	2309.7	2331.9	2258.9
90 th	2363.7	2333.4	2348.1	2283.8
95 th	2379.8	2357.0	2361.5	2323.4
97 th	2387.3	2359.0	2366.1	2352.9
98 th	2389.9	2368.4	2380.0	2366.2
99 th	2417.9	2380.0	2391.3	2367.8

SHOULDER FORWARD FLEXION EXTENSION (Neutral to Flexion)

Description

Area of Body:	Shoulder, arms, torso
Plane:	Sagittal
Equipment Needed:	<ul style="list-style-type: none"> • Digital inclinometer, with attached ruler • Doorway or other corner, pillar, or weighted cabinet
Movement Sequence:	<ol style="list-style-type: none"> 1. Test participant stands facing the outside edge of a door frame with outermost point (i.e., chest, toes) lightly touching the flat surface of the door frame or cabinet*. <ol style="list-style-type: none"> a. Arms should be hanging at the side, with palms backward. b. Participant should not be leaning against the wall or using it for support. 2. Participant raises <u>both</u>** arms forward and upward as far as possible while in a standing position <ol style="list-style-type: none"> a. Arms should follow the sagittal plane of the body. b. Elbow and wrist should stay straight. c. Trunk should stay erect. d. When arms are being raised, palms should face the floor, and when arms are overhead, they should face the direction the participant is facing. 3. Participant holds maximum upward position. <p>* Due to the body armor and/or participant's body type, toes, abdomen, sternum, and nose may not all be able to touch wall. Tester must utilize the outermost point and must ensure the participant is in a vertical plane.</p> <p>** If door frame (or other device) does not allow for both arms to be raised, just the right arm can be used, although the measurer should ensure that the participant does not lean toward their left side.</p> <p>Note: This movement can be conducted with participant seated in a chair without arms, but special care must be taken to ensure there are no extraneous movements. Participant should sit in anthropometric position, with his/her back lightly touching chair back.</p>

SHOULDER FORWARD FLEXION EXTENSION

Measurement Sequence:	<ol style="list-style-type: none"> 1. Place inclinometer on participant's right arm, just above the elbow. <ol style="list-style-type: none"> a. With dial on lateral surface, ruler should follow the humerus and fall in line with the ball and socket of the shoulder. b. Participant must stand with arm against side, elbow and wrist straight. 2. Set inclinometer to "0". 3. Measure degrees of movement when participant reaches maximum position; this position should be greater than parallel to the floor/perpendicular to the body, but is unlikely to go farther than in line with the body (although some individuals who are double jointed can exceed this range).
Potential Causes of Restriction:	<ul style="list-style-type: none"> • Armor chest breadth is wide, and/or front plate is too wide. • Arm hole opening is narrow. • Strap going over the shoulder of the vest is wide.
Cautions:	<ul style="list-style-type: none"> • Ensure no extension of the back. • Ensure no arm rotation/shoulder socket rotation – movement should be in one plane only. • Ensure no movement out of the median plan.
Real World Equivalents:	<ul style="list-style-type: none"> • Lifting a box to a high shelf • Operating controls over head
Data Collection:	Measurement 1 Measurement 2 Measurement 3 Mean 1-3 There is no manipulation of the data. Three measurements are taken, and a mean is calculated and used as the score.

SHOULDER FORWARD FLEXION EXTENSION



Figure 30: Shoulder Forward Flexion Extension

Summary Statistics

Table 19: Shoulder Forward Flexion Extension, measured in degrees

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
N	111	68	67	95
Mean	169.4	146.5	154.1	144.8
Degradation of Mean	-	13.5%	9.0%	14.5%
Min	142.0	101.3	132.3	110.0
Max	184.3	172.3	179.3	176.7
SD	8.8	14.0	11.6	16.1
Skewness (Skew SD)	-0.63 (0.23)	-0.75 (0.29)	0.70 (0.29)	-0.04 (0.25)

*Mean, Min, Max, and SD data in degrees

SHOULDER FORWARD FLEXION EXTENSION

Table 20: Percentiles for Shoulder Forward Flexion Extension

Percentile	Degrees			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	145.3	111.3	132.6	113.1
2 nd	148.7	116.4	132.8	114.2
3 rd	150.3	117.0	133.0	116.3
5 th	153.9	121.2	135.0	118.7
10 th	159.0	130.2	137.6	123.1
15 th	160.2	132.8	143.0	125.8
20 th	162.0	134.5	146.1	130.4
25 th	163.5	137.0	147.2	133.2
30 th	165.3	139.1	147.6	135.1
35 th	166.2	143.0	150.0	136.3
40 th	167.7	146.0	151.0	141.5
45 th	168.7	147.9	152.0	144.1
50 th	169.7	149.7	153.3	147.0
55 th	171.5	150.8	154.5	148.6
60 th	172.3	152.2	156.1	149.8
65 th	173.9	153.6	157.7	151.7
70 th	175.3	156.2	161.0	153.0
75 th	176.7	157.0	162.3	155.4
80 th	178.0	157.3	163.6	158.2
85 th	178.9	160.2	167.1	161.9
90 th	180.0	163.0	169.5	164.7
95 th	181.2	165.7	173.7	171.9
97 th	181.9	167.0	175.0	174.9
98 th	182.8	168.1	176.2	176.0
99 th	183.9	169.9	177.6	176.3

SHOULDER FORWARD EXTENDED REACH

Description

Area of Body:	Shoulder, arms, torso
Plane:	Frontal
Equipment Needed:	<ul style="list-style-type: none"> • Corner with wall next to right arm • Wall scale (horizontal) • 20cm block • Measuring block
Movement Sequence:	<ol style="list-style-type: none"> 1. A 20 cm block is placed against the wall that test participant leans against. 2. Participant stands erect in a corner looking straight ahead. <ol style="list-style-type: none"> a. Feet are slightly spread, and the back of his/her heels are 20 cm from the back wall (touching the block). b. Participant leans back against the wall. c. The center of the upper back and left shoulder remain against the wall. 3. Participant's right arm and hand, with the palm down and fingers together, are stretched forward horizontally against a scale on the side wall. <ol style="list-style-type: none"> a. The arm should be parallel with the floor so the test participant does not reach higher or lower. 4. Participant's left shoulder (non-reaching arm) is held against the rear wall by the measurer to ensure that it does not move forward. <ol style="list-style-type: none"> a. The right shoulder is allowed to roll forward as the participant reaches, but the center of his/her back should stay against the wall.
Measurement Sequence:	<ol style="list-style-type: none"> 1. Measurer must hold the left shoulder against the wall, while the participant reaches with his/her other arm. 2. When the participant reaches the maximum distance possible, the tester should place a block connecting the tip of the longest finger and the wall. <ol style="list-style-type: none"> a. Tester ensures that the measuring block is parallel to the floor and not at an angle. b. Tester may have to hold participant's shoulder. <p>Additionally, a standard measurement should be taken (with calipers) for each size of each configuration (not for all participants) of the thickness of the back armor and plate at the location on the vest where the participant leans against the wall.</p>

SHOULDER FORWARD EXTENDED REACH

Cautions:	<ul style="list-style-type: none"> • Ensure that the measuring block is, flat against the wall, parallel to the floor and not at an angle. • Center of back should not leave wall. • Tell the participant that it is acceptable for the shoulder of his/her reaching arm to lift off the wall, but the center of the back should stay against the wall.
Potential Causes of Restriction:	<ul style="list-style-type: none"> • Armor chest breadth is wide, and/or front plate is too wide. • Strap going over the shoulder of the vest is wide.
Real World Equivalents:	<ul style="list-style-type: none"> • Reaching to operate controls in front of and to the sides of an operator • Lifting boxes
Data Collection:	<div style="display: flex; justify-content: space-around; align-items: center;"> Measurement 1-Bulk Depth Measurement 2-Bulk Depth </div> <div style="display: flex; justify-content: space-around; align-items: center;"> Measurement 3-Bulk Depth Mean 1-3 </div> <p>The ensemble worn varies in its thickness and affects the participant's starting point when he/she reaches forward. To allow the results to be compared against configurations, a bulk or thickness measurement of the body armor must be taken, using calipers. That measurement is subtracted from the observed measurement. Those three new scores are averaged, and a mean is calculated. This mean is used as the score.</p>

SHOULDER FORWARD EXTENDED REACH



(a)



(b)

Figure 31: Shoulder Forward Extended Reach. (a) View from straight on; (b) View from participant's side

SHOULDER FORWARD EXTENDED REACH

Summary Statistics

Table 21: Shoulder Forward Extended Reach, measured in mm

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates†	BAPL 5: IOTV with front, back, & side plates
N	113	67	67	95
Mean	941.8	921.8	961.8	919.8
Degradation of Mean	-	2.1%	-2.1%	2.3%
Min	771.0	818.7	847.7	687.0
Max	1059.0	1045.0	1068.0	1029.7
SD	58.9	50.3	50.9	56.1
Skewness (Skew SD)	-0.55 (0.23)	-0.00 (0.29)	-0.02 (0.29)	-0.89 (0.25)

*Mean, Min, Max, and SD data in mm

†Participants had a better mean in the BAPL 3 configuration than they had in the baseline (BAPL 0) configuration; however the N was smaller for BAPL 3 than for BAPL 0. When the same 67 individuals are used, the BAPL 0 mean score increases to 953 mm.

SHOULDER FORWARD EXTENDED REACH

Table 22: Percentiles for Shoulder Forward Extended Reach scores

Percentile	mm			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	791.0	828.1	864.6	781.7
2 nd	810.3	834.9	874.8	796.8
3 rd	825.1	839.3	877.9	815.0
5 th	827.4	843.8	883.9	827.2
10 th	861.4	850.3	890.2	855.3
15 th	878.7	861.6	898.7	865.6
20 th	889.4	877.5	916.7	880.3
25 th	912.0	889.7	928.9	889.2
30 th	923.1	896.9	935.2	893.5
35 th	929.7	908.4	944.3	901.2
40 th	934.6	912.2	946.7	906.5
45 th	941.9	915.5	954.8	918.3
50 th	946.3	921.7	960.0	927.3
55 th	953.5	928.6	968.1	931.9
60 th	962.2	937.3	974.5	934.6
65 th	968.5	944.2	978.7	942.3
70 th	973.7	951.5	985.8	952.4
75 th	979.0	963.4	997.7	960.3
80 th	990.9	966.8	1013.9	965.5
85 th	1002.7	977.5	1024.8	972.8
90 th	1012.9	987.9	1031.1	984.9
95 th	1022.1	996.4	1038.5	998.8
97 th	1036.9	1000.0	1043.0	1002.4
98 th	1048.5	1004.0	1051.3	1010.1
99 th	1052.5	1018.9	1059.6	1019.0

SHOULDER BACKWARD EXTENSION (Neutral to Flexion)

Description

Area of Body:	Shoulder, arms, torso
Plane:	Sagittal
Equipment Needed:	<ul style="list-style-type: none"> • Digital inclinometer with ruler • Doorway or other corner
Movement Sequence:	<ol style="list-style-type: none"> 1. Test participant stands facing the outside edge of a door frame with the outermost point (i.e., chest, toes) lightly touching the flat surface of the door frame or cabinet.* <ol style="list-style-type: none"> a. Participant's arms should be hanging at the side. b. Participant should not be leaning against the wall. 2. Participant places his/her right arm against his/her side with the elbow straight and the arm straight down. 3. Participant rotates arm until the palm of the hand faces outward. <ol style="list-style-type: none"> a. Thumb should be facing behind the participant. b. Fingers should be pointing toward the ground. 4. Participant raises the entire right arm (only the right arm) backwards and upwards as far as possible. <ol style="list-style-type: none"> a. Elbow should be straight. <p>* Due to the body armor, toes, abdomen, sternum and nose may not all be able to touch wall. Tester must utilize the outermost point and ensure the participant is in a vertical plane.</p> <p>Note: This movement can also be conducted with participant seated in a chair without arms, but special care must be taken to ensure there are no extraneous movements. Participant should sit in the anthropometric position, with his/her back lightly touching chair back. The participant may need to position him/herself off center on the chair, so body hangs slightly over the end of the seat.</p>
Measurement Sequence:	<ol style="list-style-type: none"> 1. Test participant stands erect against wall. Arm is rotated until palm faces outward and thumb points behind the participant. 2. Inclinometer is placed on right arm, after the hand has been rotated, just above elbow, and set to "0". <ol style="list-style-type: none"> a. Arm starts perpendicular to floor. b. Ruler attached to the goniometer should follow the humerus to the ball and socket of the shoulder joint. 3. Measurement is taken when participant moves arm as far back as possible.

SHOULDER BACKWARD EXTENSION

Cautions:	<ul style="list-style-type: none"> • Ensure no extension of the back/forward leaning. • Ensure no arm rotation/shoulder extension. • Ensure elbow remains stiff. • Ensure palm faces out with thumb pointing behind participant. • Ensure participant stays within the plane. • Ensure arm does not go out to the side, either behind participant or out wide.
Potential Causes of Restriction:	<ul style="list-style-type: none"> • Armor back breadth and/or plate is wide. • Arm hole opening is narrow.
Real World Equivalents:	<ul style="list-style-type: none"> • Reaching behind to operate controls
Data Collection:	<p>Measurement 1 Measurement 2 Measurement 3 Mean 1-3</p> <p>There is no manipulation of the data. Three measurements are taken, and a mean is calculated and used as the score.</p>



Figure 32: Shoulder Backward Extension

SHOULDER BACKWARD EXTENSION

Summary Statistics

Table 23: Shoulder Backward Extension, measured in degrees

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
N	111	68	67	95
Mean	40.6	35.4	37.0	37.8
Degradation of Mean	-	12.8%	8.9%	6.9%
Min	22.0	16.0	22.7	15.7
Max	75.3	47.7	48.7	66.0
SD	8.6	6.9	5.9	8.2
Skewness (Skew SD)	1.1 (0.23)	-0.52 (0.29)	-0.32 (0.29)	0.48 (0.25)

*Mean, Min, Max, and SD data in degrees

SHOULDER BACKWARD EXTENSION

Table 24: Percentiles for Shoulder Backward Extension scores

Percentile	Degrees			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	25.8	18.9	22.9	23.2
2 nd	26.8	20.4	23.7	23.7
3 rd	27.1	20.7	25.3	25.0
5 th	28.0	22.1	26.6	25.9
10 th	29.7	27.7	28.7	28.3
15 th	32.0	29.0	31.2	31.0
20 th	34.3	30.7	33.1	31.3
25 th	35.7	31.0	34.2	32.2
30 th	37.0	32.1	35.0	33.3
35 th	38.3	32.9	35.3	34.0
40 th	39.0	34.0	35.5	34.7
45 th	39.7	35.0	35.7	36.0
50 th	40.3	35.7	37.0	37.0
55 th	41.3	36.8	37.7	38.5
60 th	41.7	37.6	38.0	40.0
65 th	42.3	39.1	39.9	41.0
70 th	43.0	39.7	40.7	41.9
75 th	44.3	40.3	41.4	42.5
80 th	45.3	41.5	41.9	43.4
85 th	46.9	42.7	43.7	45.7
90 th	50.0	44.0	44.3	47.1
95 th	52.7	45.4	46.1	51.7
97 th	60.8	45.7	46.7	55.0
98 th	64.0	45.9	46.9	56.4
99 th	71.0	46.5	47.6	57.5

SHOULDER FORWARD CROSS BODY EXTENSION (Sitting)

Description

Area of Body:	Shoulder, Arms, Torso
Plane:	Transverse
Equipment Needed:	<ul style="list-style-type: none"> • Protractor goniometer • Seat or stool • Sturdy ladder or step stool for measurer to stand on (optional)
Movement Sequence::	<ol style="list-style-type: none"> 1. Test participant sits in an anthropometric seated position, with his/her right arm raised out to the side, in line with shoulders <ol style="list-style-type: none"> a. Arm is parallel to the floor. b. Palm faces the floor. 2. The test participant moves arm across the front of body, as far to the left as possible. <ol style="list-style-type: none"> a. Elbow and wrist are kept straight. <p>Note: This movement can also be conducted when participant is standing, but special care must be taken to ensure there are no extraneous movements. Participant should stand in the anthropometric position, with his/her back lightly touching a wall.</p>
Measurement Sequence::	<ol style="list-style-type: none"> 1. Measurer stands over the participant and holds the goniometer over the acromion. <ol style="list-style-type: none"> a. Goniometer should not sit on the participants shoulder 2. Arms of the goniometer, when together, should follow the humerus. 3. As participant moves arm across his/her body, second arm of the goniometer should follow the humerus while the first arm stays in the original location. <ol style="list-style-type: none"> a. Data collector or second measurer may be needed to aid in ensuring the first arm of the goniometer does not move. 4. Measurement should be taken at the participant's maximum arm movement position.
Cautions:	<ul style="list-style-type: none"> • Elbow should not be flexed. • Measurer needs to ensure that the placement of the non-moving arm of the goniometer does not migrate. • When the goniometer is initially lined up, it should fall in line with the shoulders, not behind or forward, and it should be held level to the floor. • Participant should look straight ahead.

SHOULDER FORWARD CROSS BODY EXTENSION

Potential Causes of Restriction:	<ul style="list-style-type: none">• Armor chest breadth is too wide.• Chest breadth is wide and/or is same width as front plate.• Arm hole is narrow.
Real World Equivalents:	<ul style="list-style-type: none">• Reaching to operate controls inside a vehicle or aircraft• Turning a steering wheel
Data Collection:	Measurement 1 Measurement 2 Measurement 3 Mean 1-3 There is no manipulation of the data. Three measurements are taken, and a mean is calculated and used as the score.

SHOULDER FORWARD CROSS BODY EXTENSION



Figure 33: Shoulder Forward Cross Body Extension

SHOULDER FORWARD CROSS BODY EXTENSION

Summary Statistics

Table 25: Shoulder Forward Cross Body Extension, measured in degrees

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
N	111	68	67	95
Mean	122.8	109.3	113.0	103.7
Degradation of Mean	-	11.0%	8.0%	15.6%
Min	96.3	84.0	83.0	72.0
Max	96.3	84.0	83.0	72.0
SD	148.0	133.0	137.0	129.7
Skewness (Skew SD)	-0.34 (0.23)	-0.18 (0.29)	-0.37 (0.29)	-0.24 (0.25)

*Mean, Min, Max, and SD data in degrees

SHOULDER FORWARD CROSS BODY EXTENSION

Table 26: Percentiles for Shoulder Forward Cross Body Extension scores

Percentile	Degrees			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	100.0	84.2	87.4	72.3
2 nd	100.3	85.2	90.0	79.1
3 rd	102.1	86.7	90.7	80.8
5 th	103.5	87.9	92.8	86.7
10 th	107.0	93.6	97.0	91.1
15 th	111.2	97.5	101.9	92.0
20 th	112.3	101.5	104.1	93.9
25 th	116.2	104.0	106.2	96.0
30 th	117.3	104.6	107.9	97.8
35 th	118.7	106.2	108.7	99.7
40 th	120.3	107.4	110.6	102.0
45 th	122.7	108.2	112.5	103.2
50 th	124.7	110.0	114.7	105.0
55 th	125.7	110.6	116.3	105.6
60 th	126.7	112.2	117.2	106.9
65 th	128.3	113.3	118.3	107.7
70 th	129.3	115.7	119.4	109.2
75 th	131.4	117.3	120.7	111.0
80 th	133.0	118.1	122.2	111.4
85 th	133.7	121.1	123.8	114.7
90 th	135.3	123.5	125.6	118.7
95 th	137.7	128.5	129.9	123.2
97 th	138.1	129.0	131.1	124.1
98 th	139.7	130.5	133.7	124.8
99 th	140.3	131.8	135.7	125.9

SHOULDER CROSS BODY REACH (Sitting)

Description

Area of Body:	Shoulder, arms, torso
Plane:	Transverse
Equipment Needed:	<ul style="list-style-type: none"> • Wall • Measuring stick and/or 20 cm block with scale • Chair (without back), stool, or table to sit on
Movement Sequence:	<ol style="list-style-type: none"> 1. Test participant is in anthropometric sitting position with his/her back to a wall. <ol style="list-style-type: none"> a. Participant's back should be 20 cm away from the wall. <ol style="list-style-type: none"> i. 20 cm block can be placed between the upper or middle back and the wall to ensure that distance stays 20 cm; participant should lean against the block to hold it in place but should sit close to upright. 2. Participant raises his/her right arm. 3. Humerus and elbow reach out straight ahead, perpendicular to the torso and parallel to the floor. 4. Participant reaches over his/her opposite (left) shoulder. <ol style="list-style-type: none"> a. Elbow is bent. b. Hand is flat, fingers outstretched, parallel to the floor. c. Arm is parallel to the floor. 5. Participant reaches as far over his/her shoulder as possible, in an attempt to touch the wall with the longest finger.
Measurement Sequence:	<ol style="list-style-type: none"> 1. When participant reaches over shoulder, tester measures distance from longest fingertip to the wall. 2. Measurement board/20 cm block with scale is placed against participant's upper back. <ol style="list-style-type: none"> a. If a scale is added to the block, it can be used, instead of a measuring stick, to measure distance between the longest finger and the wall.

SHOULDER CROSS BODY REACH

<p>Cautions:</p>	<ul style="list-style-type: none"> • Ensure that participant sits up straight and does not lean forward or backward; participant should be holding the 20 cm block in place, but torso should be upright. • Participant may have a hard time keeping the hand steady. Take measurement at a distance where the participant can hold his/her hand for 1-2 s. <ul style="list-style-type: none"> ○ Participant often makes an initial forward motion, but is unable to hold it, and the hand slides back to a location that he/she can hold for 1-2 s. Attempt to use the second location, even if their hand continues to slip back from there when holding it for longer periods; a quick measurement by the recorder is necessary. • Ensure that participant looks straight ahead. • Ensure that arm is parallel to the floor, i.e., elbow not pointed up or down.
<p>Potential Causes of Restriction:</p>	<ul style="list-style-type: none"> • Armor chest breadth is wide, and/or front plate is too wide. • Shoulder strap is wide.
<p>Real World Equivalents:</p>	<ul style="list-style-type: none"> • Reaching to operate controls • Reaching to shoulder to adjust hydration tubing
<p>Data Collection:</p>	<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>Measurement 1-Bulk Depth Measurement 3-Bulk Depth</p> <p>The ensemble worn varies in its thickness and affects the participant's starting point (distance from wall). To allow the results to be compared against configurations, a measurement of the thickness of the body armor is taken, using calipers. That measurement is subtracted from the observed measurement taken. Those three new scores are averaged, and a mean is calculated. This mean is used as the score.</p> </div> <div style="width: 45%;"> <p>Measurement 2-Bulk Depth Mean 1-3</p> </div> </div>
<p>Reminder:</p>	<p>The larger the score, the worse the performance.</p>

SHOULDER CROSS BODY REACH



Figure 34: Shoulder Cross Body Reach

Summary Statistics

Table 27 Shoulder Cross Body Reach, measured in mm

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
N	113	67	67	95
Mean	182.4	262.8	277.8	302.8
Degradation of Mean	-	44.1%	52.3%	66.0%
Min	77	158.7	167.7	154.3
Max	346.3	402.3	402.3	438.0
SD	47.1	52.5	48.0	50.7
Skewness (Skew SD)	0.57 (0.23)	0.35 (0.29)	0.18 (0.29)	0.10 (0.25)

*Mean, Min, Max, and SD data in mm

Note: Larger measurement reflects increased restriction.

SHOULDER FORWARD CROSS BODY REACH

Table 28: Percentiles for Shoulder Cross Body Reach

Percentile	mm			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	307.6	378.6	384.9	408.6
2 nd	285.0	366.3	373.1	403.2
3 rd	274.5	364.9	367.2	402.1
5 th	259.9	351.1	348.0	395.1
10 th	245.9	339.8	338.1	366.3
15 th	228.6	321.5	328.4	353.0
20 th	215.1	315.5	317.2	344.3
25 th	206.7	304.6	311.7	333.3
30 th	202.5	283.2	305.5	325.1
35 th	196.7	277.7	301.4	316.4
40 th	191.1	265.2	291.7	312.3
45 th	184.3	261.2	280.1	304.4
50 th	178.3	255.9	272.7	299.3
55 th	174.9	250.9	267.5	297.8
60 th	172.5	247.5	261.2	291.2
65 th	164.5	242.9	257.1	284.5
70 th	154.5	236.9	249.8	274.0
75 th	146.0	228.9	240.8	270.4
80 th	141.2	220.9	235.3	263.7
85 th	131.9	216.8	232.1	256.0
90 th	123.3	203.3	222.9	243.1
95 th	117.4	177.9	207.8	221.7
97 th	112.6	174.0	191.0	216.7
98 th	107.7	164.8	191.0	211.3
99 th	92.6	159.6	183.1	201.3

Note: Larger measurement reflects increased restriction.

HIP FLEXION (Neutral to Flexion)

Description

Area of Body:	Torso, hip, leg
Plane:	Sagittal
Equipment Needed:	<ul style="list-style-type: none"> • Digital inclinometer • Wall • Chair, with back (optional)
Movement Sequence:	<ol style="list-style-type: none"> 1. Participant stands with back against a wall (or other flat object). <ol style="list-style-type: none"> a. Participant can grasp a support (such as the back of a chair) for balance. b. Right arm should be folded in front of stomach to keep it out of the way of the measurer. 2. Participant raises right knee as high as possible, and allows the knee to bend/hang freely toward the ground.
Measurement Sequence:	<ol style="list-style-type: none"> 1. As Participant lifts leg, the goniometer is positioned at the side of the leg, just above the knee, with the ruler following the femur. 2. Measurement is taken when the participant raises his/her knee to the maximum position. <ol style="list-style-type: none"> a. This measurement is the angle of movement of the femur.
Cautions:	<ul style="list-style-type: none"> • Participant must stand up straight and not lean forward, backward, or to either side. • Wall should not be used for support. • Participant should keep standing with the knee straight and locked. • Participant should look straight ahead.
Potential Causes of Restriction:	<ul style="list-style-type: none"> • Vest is long. • Side plates hang lower than the vest. • Front plate is long or sits too low on body.
Real World Equivalents:	<ul style="list-style-type: none"> • Lifting leg to step into a vehicle or over an object

HIP FLEXION

Data Collection:	Measurement 1	Measurement 2	Measurement 3	Mean 1-3
	There is no manipulation of the data. Three measurements are taken, and a mean is calculated and used as the score.			
	Note: Some literature recommends measuring from the position of the spine, in effect measuring the opposite arch, and in that case, the smaller the angle, the more ROM. This may lead to some discrepancies in literature data for normal ranges.			



Figure 35: Hip Flexion

HIP FLEXION

Summary Statistics

Table 29: Hip Flexion, measured in degrees

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
N	111	68	67	95
Mean	103.9	101.4	102.6	98.8
Degradation of Mean	-	2.4%	1.3%	4.9%
Min	78.0	74.0	73.3	68.0
Max	131.0	122.7	137.7	120.0
SD	10.24	10.6	11.4	10.3
Skewness (Skew SD)	-0.15 (0.23)	-0.40 (0.29)	-0.18 (0.29)	-0.38 (0.25)

*Mean, Min, Max, and SD data in degrees

HIP FLEXION

Table 30: Percentiles for Hip Flexion scores in degrees

Percentile	Degrees			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	82.0	75.2	75.1	76.2
2 nd	82.4	75.8	76.1	77.0
3 rd	83.5	76.0	76.3	77.2
5 th	85.0	79.9	82.2	81.0
10 th	90.7	90.7	90.2	85.0
15 th	94.2	93.0	91.9	90.0
20 th	95.3	94.7	92.8	90.9
25 th	96.2	95.7	95.7	92.8
30 th	97.7	97.7	96.7	95.0
35 th	100.5	98.6	99.1	96.0
40 th	102.7	99.0	101.0	97.1
45 th	103.7	99.9	102.6	98.4
50 th	104.7	100.7	104.3	99.0
55 th	105.9	102.5	105.3	100.0
60 th	107.3	103.2	105.5	100.7
65 th	108.3	104.3	106.7	103.0
70 th	109.3	106.0	108.4	104.6
75 th	110.5	107.3	109.5	105.7
80 th	112.0	108.5	111.9	106.8
85 th	114.9	112.5	113.3	109.9
90 th	116.3	116.1	115.3	111.7
95 th	120.9	118.9	117.7	115.4
97 th	121.8	120.3	118.7	117.4
98 th	122.0	120.3	120.1	117.8
99 th	123.2	121.1	126.5	118.4

4.2 Natural Movements

STANDING STATURE (with Footwear)

Description

Area of Body:	Whole body
Equipment Needed:	Anthropometer
Movement Sequence:	Test participant stands in anthropometric position with boots on and head in the Frankfurt plane.
Measurement Sequence:	Stature is measured using the anthropometer.
Cautions:	Test participant should be standing up straight, with the head in the Frankfurt plane.
Potential Causes of Restriction:	<ul style="list-style-type: none">• Weight of armor is not properly distributed.• Curvature of plate does not match body or is not placed correctly on body.
Real World Equivalents:	Standing
Controlled Movement Components:	n/a
Pass/Fail Criteria:	Does the participant feel like he/she is being pulled forward by the armor? Does the participant feel like he/she is being pulled backward by the armor?
Data Collection:	Measurement 1 Note: Only one measurement was taken for this movement.

STANDING STATURE



Figure 36: Standing Stature

Summary Statistics

Table 31: Standing Stature, measured in mm

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
N	110	68	67	95
Mean	1778.8	1784.5	1784.7	1774.7
Degradation of Mean	-	-0.3%	-0.3%	-0.2%
Min	1570.0	1655.0	1648.0	1558.0
Max	1946.0	1943.0	1938.0	1945.0
SD	71.8	65.1	67.3	72.5
Skewness (Skew SD)	-0.31 (0.23)	0.24 (0.29)	0.11 (0.29)	-0.29 (0.25)

*Mean, Min, Max, and SD data in mm

STANDING STATURE

Table 32: Percentiles for Standing Stature scores

Percentile	mm			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	1589.2	1658.4	1652.0	1573.0
2 nd	1625.0	1669.4	1655.3	1605.7
3 rd	1646.5	1686.2	1657.9	1645.3
5 th	1658.9	1692.6	1689.9	1670.2
10 th	1693.4	1706.8	1699.2	1688.6
15 th	1709.0	1714.0	1714.6	1708.2
20 th	1720.8	1729.2	1732.0	1721.8
25 th	1734.0	1736.0	1736.5	1728.0
30 th	1741.1	1741.0	1742.0	1735.2
35 th	1752.3	1755.2	1750.2	1743.6
40 th	1759.6	1764.0	1761.6	1753.6
45 th	1773.1	1772.4	1767.0	1767.6
50 th	1785.5	1782.0	1781.0	1778.0
55 th	1797.9	1798.0	1792.6	1788.0
60 th	1801.4	1801.8	1801.2	1791.2
65 th	1811.0	1806.0	1806.7	1801.1
70 th	1814.0	1809.8	1817.0	1807.0
75 th	1822.3	1835.0	1833.5	1820.0
80 th	1835.0	1850.4	1850.4	1839.4
85 th	1854.7	1867.4	1864.7	1856.4
90 th	1877.2	1880.6	1881.6	1874.0
95 th	1887.2	1887.8	1886.8	1878.6
97 th	1898.7	1898.6	1900.0	1900.0
98 th	1901.5	1903.5	1900.0	1901.8
99 th	1917.5	1917.8	1912.9	1916.8

STAND – PRONE - STAND

Description

Area of Body:	Whole body, torso, arms, legs
Equipment Needed:	None
Movement Sequence:	<ol style="list-style-type: none"> From the standing position, participant drops to the prone position. <ol style="list-style-type: none"> Participant lies on his/her stomach on the ground with legs outstretched. Participant may kneel down on one knee to get into prone position. Participant rises from the prone position to standing position. <ol style="list-style-type: none"> Participant may kneel down on one knee when rising from the prone position.
Measurement Sequence:	No objective measurement
Cautions:	-
Potential Causes of Restriction:	<ul style="list-style-type: none"> Vest is long. Side plates are positioned too low or are too long Vest is rigid in the stomach/chest area. Front plate is too long.
Real World Equivalents:	<ul style="list-style-type: none"> Lying on the floor and getting up
Controlled Movement Components:	<ul style="list-style-type: none"> Upper leg/hip flexion Shoulder forward extension
Pass/Fail Criteria:	<p>Does the side plate dig into the thigh? Does the soft armor on the front of the vest press into the thigh?</p>

STAND – PRONE – STAND



Figure 37: Prone to Standing Movement (with optional intermediate kneel on one knee)

FIVE STEPS FORWARD (Walk - Forward)

Description

Area of Body:	Legs, hips
Equipment Needed:	<ul style="list-style-type: none"> • Floor scale (10 m) • T-bar measuring stick • Wall (optional) • Large room with flat floor surface, non-carpeted preferred
Movement Sequence:	<ol style="list-style-type: none"> 1. Test participant stands with the back edge of his/her heels at the “0” mark of the floor scale. <ol style="list-style-type: none"> a. Ideally, the “0” mark should be against a wall. b. Feet should be together at start. 2. Test participant takes five exaggerated or maximum steps, each as far forward as possible, starting with the right foot. <ol style="list-style-type: none"> a. After each step, the feet are brought together before participant proceeds. b. The participant should not “lunge”, as lunging decreases the length of the steps and causes unnecessary fatigue.
Measurement Sequence:	<ol style="list-style-type: none"> 1. The distance from the heel of the foot at first step to the heel of the foot at completion of the fifth step is taken. <ol style="list-style-type: none"> a. If feet are not directly together, use the heel with the shorter distance. 2. T-bar is rested against back of participant’s heel, and the vertical and horizontal edges of the measurement device are lined up with the lines of the floor scale.
Cautions:	<ul style="list-style-type: none"> • If the participant loses his/her balance or stumbles, the task should be restarted.
Potential Causes of Restriction:	<ul style="list-style-type: none"> • Vest is long, causing hips to be encompassed by vest torso. • Front plate is long or positioned too low on torso. • Weight of the armor is not well distributed.
Real World Equivalents:	<ul style="list-style-type: none"> • Walking, marching, jogging/running
Controlled Movement Components:	<ul style="list-style-type: none"> • Upper leg/hip flexion

FIVE STEPS FORWARD

Data Collection:	Measurement 1	Measurement 2	Measurement 3	Mean 1-3
	There is no manipulation of the data. Three measurements are taken, and a mean is calculated and used as the score.			



Figure 38: Five Steps Forward

FIVE STEPS FORWARD

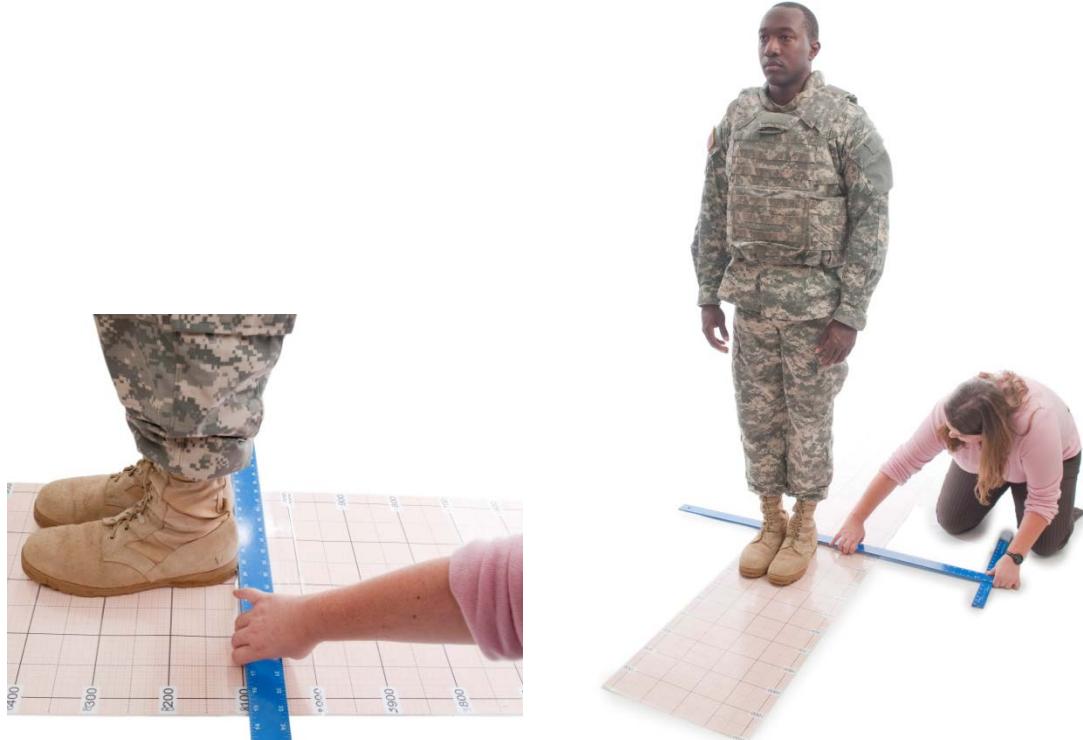


Figure 38: Five Steps Forward - Continued

Summary Statistics

Table 33: Five Steps Forward, measured in mm

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
N	112	67	67	96
Mean	7290.7	7359.5	7347.6	7112.6
Degradation of Mean	-	-0.9%*	-0.7%*	2.4%
Min	5362.0	6053.0	6052.7	5026.7
Max	9095.3	9056.7	8551.3	8567.3
SD	777.8	633.4	562.0	673.2
Skewness (Skew SD)	0.00 (0.23)	0.40 (0.29)	-0.12 (0.29)	-0.19 (0.25)

*Mean, Min, Max, and SD data in mm

Table 34: Percentiles for Five Steps Forward scores

Percentile	mm			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	5451.9	6161.3	6114.7	5742.1
2 nd	5532.0	6227.7	6201.1	5785.4
3 rd	5733.8	6253.3	6313.3	5952.3
5 th	6176.7	6337.0	6396.7	6037.1
10 th	6298.9	6534.2	6645.8	6225.7
15 th	6532.2	6689.7	6682.4	6472.6
20 th	6667.3	6830.9	6863.6	6515.7
25 th	6790.8	6952.3	6957.0	6605.3
30 th	6886.8	7076.8	7062.5	6730.3
35 th	6983.5	7122.5	7214.5	6795.3
40 th	7110.7	7187.9	7237.9	6990.3
45 th	7154.6	7203.1	7269.6	7079.0
50 th	7261.4	7254.2	7384.7	7173.3
55 th	7334.8	7358.9	7411.8	7233.7
60 th	7419.0	7480.4	7501.5	7279.0
65 th	7537.3	7519.5	7556.4	7387.2
70 th	7721.7	7566.1	7672.2	7501.4
75 th	7834.7	7733.6	7710.7	7567.0
80 th	7941.1	7883.4	7865.5	7627.3
85 th	8063.5	7927.4	7921.5	7746.7
90 th	8292.9	8137.7	8109.4	8026.3
95 th	8682.7	8545.1	8261.6	8163.2
97 th	8795.1	8707.1	8281.4	8302.6
98 th	8907.2	8768.9	8303.5	8344.3
99 th	8943.2	8887.9	8394.9	8505.9

JOG

Description

Area of Body:	Whole body
Equipment Needed:	<ul style="list-style-type: none"> Large room with flat floor surface; non-carpeted preferred
Movement Sequence:	1. Test participant jogs approximately 20 m, raising legs, twisting torso, and moving arms backward and forward.
Measurement Sequence:	No objective measurement
Cautions:	-
Potential Causes of Restriction:	<ul style="list-style-type: none"> Armor chest breadth is wide and/or is same width as front plate. Armor is too long. Weight of armor is not well distributed.
Real World Equivalents:	<ul style="list-style-type: none"> Jogging, running, sprinting
Controlled Movement Components:	<ul style="list-style-type: none"> Upper leg/hip flexion Thoracic/lumbar spine rotation Upper arm/shoulder forward flexion extension Upper arm/shoulder backward extension
Pass/Fail Criteria:	<p>Does the armor bounce (move up and down) on the participant's shoulders, chest, or back?</p> <p>Does the armor hit the participant's leg or stomach?</p> <p>Can the participant turn/rotate torso in the manner required?</p>

JOG



Figure 39: Jogging

TRUNK FLEXION - STANDING (Bending at Waist-Standing)

Description

Area of Body:	Hip, torso
Equipment Needed:	<ul style="list-style-type: none"> • Biometric box or other platform <ul style="list-style-type: none"> ◦ Box should be at least 400 mm tall. (Height of the box is subtracted during the data manipulation.) ◦ Attached vertical scale (optional) • Measuring stick/ruler or anthropometer
Movement Sequence:	<ol style="list-style-type: none"> 1. Test participant stands on box. <ol style="list-style-type: none"> a. Feet are parallel and a shoulder width apart. b. Toes should be at the edge of the box facing the upright measurement stick/vertical scale. 2. Test participant attempts to touch toes by bending at the waist. <ol style="list-style-type: none"> a. Keep knees stiff/straight. b. Perform two preliminary toe touches prior to starting measurements. 3. Participant keeps hands together and slides palms down the outside surface of the board/box. 4. Participant holds lowest point for a few seconds before straightening body.
Measurement Sequence:	<ol style="list-style-type: none"> 1. The distance between the longest fingertip and the floor is measured. 2. Test participant stands on block to allow for flexibility/movement beyond toes. <p>Note: Participant should perform this movement two to three times before being measured in order to loosen the muscles.</p>
Cautions:	<ul style="list-style-type: none"> • Participant should not bend knees. • Anthropometer should be straight, perpendicular to the floor.
Potential Causes of Restriction:	<ul style="list-style-type: none"> • Vest is long. • Side plates are long or hang low on body. • Front plate is long or sits low on torso. • Weight of armor is not well distributed. • Vest is rigid in the stomach/chest area. • Shoulder strap is wide.
Real World Equivalents:	<ul style="list-style-type: none"> • Bending down to pick up an item off the floor.

TRUNK FLEXION - STANDING

Controlled Movement Components:	<ul style="list-style-type: none"> • Hip flexion • Shoulder forward extension
Data Collection:	<p>Measurement 1-platform height Measurement 2-platform height Measurement 3-platform height Mean 1-3</p> <p>Each observed measurement has the height of the platform subtracted from it, allowing all measurements to be compared, even if the height of the platform varies. Additionally, this forces a “0” point at the bottom of the individual’s feet. Therefore many participants will have a negative score. These three derived measurements are used to calculate a mean, which is the score.</p> <p>Add 10 mm if anthropometer is used, to account for width of the bar.</p>
Reminder:	<ul style="list-style-type: none"> • Higher scores indicate poorer performance • A score below “0” (i.e., negative) indicates that the participant reached further than the level of the bottom of the feet.



Figure 40: Trunk Flexion - Standing

TRUNK FLEXION - STANDING

Summary Statistics

Table 35: Trunk Flexion – Standing, measured in mm

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
N	112	67	67	95
Mean	34.4	77.5	62.1	192.3
Degradation of Mean	-	125.3%	80.5%	459.0%
Max	432.3	331.3	384.3	651.7
Min	-183.0	-108.0	-107.0	-77.0
SD	102.9	97.1	92.6	166.2
Skewness (Skew SD)	0.88 (0.23)	0.54 (0.29)	0.85 (0.29)	0.63 (0.25)

*Mean, Min, Max, and SD data in mm

Note: The smaller the score/measurement, the better the performance. A score of 0 means the participants could reach to the level of the bottom of their feet. A negative score means that the participants could reach farther than the level of the bottom of their feet.

TRUNK FLEXION - STANDING

Table 36: Percentiles for Trunk Flexion - Standing scores

Percentile	mm			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	312.3	308.8	318.3	586.2
2 nd	272.1	283.6	274.8	575.6
3 rd	261.5	256.2	255.3	535.6
5 th	222.2	242.5	215.5	473.4
10 th	168.7	220.3	172.4	436.3
15 th	141.8	187.5	149.2	405.3
20 th	100.3	156.2	129.4	323.0
25 th	81.9	134.8	117.4	288.4
30 th	73.6	118.6	99.4	263.0
35 th	56.1	103.9	83.9	240.9
40 th	43.9	89.0	66.7	227.4
45 th	27.9	79.4	56.4	192.5
50 th	14.0	56.7	48.0	167.3
55 th	1.7	50.0	45.1	140.2
60 th	-4.2	41.6	36.4	106.5
65 th	-11.0	29.8	25.6	93.6
70 th	-19.8	16.5	9.9	80.8
75 th	-26.0	6.7	0.7	64.7
80 th	-40.0	-5.8	-20.0	40.2
85 th	-48.7	-22.7	-36.1	25.5
90 th	-74.2	-30.4	-42.3	-4.5
95 th	-124.1	-48.9	-60.4	-19.2
97 th	-134.8	-52.7	-77.5	-29.4
98 th	-142.5	-71.8	-84.1	-32.0
99 th	-171.3	-90.4	-94.0	-50.7

Note: These percentiles have been reversed because the larger the number the worse the performance.

SEATED STATURE

SEATED STATURE

Description

Area of Body:	Whole body
Equipment Needed:	<ul style="list-style-type: none"> • Chair without arms (seat pan height = 44 cm) • Anthropometer (with extended arm, if needed)
Movement Sequence:	<ol style="list-style-type: none"> 1. Test participant sits in the anthropometric position in a chair without arms.
Measurement Sequence:	<ol style="list-style-type: none"> 1. Stature is measured.
Cautions:	<ul style="list-style-type: none"> • Anthropometer should be perpendicular to the floor.
Potential Causes of Restriction:	<ul style="list-style-type: none"> • Weight of armor is not well distributed. • Vest is long. • Side and/or front plates sit low or are long. • Front/back plate curvature does not match and/or flex with participant or does not sit in the correct position on the torso.
Real World Equivalents:	<ul style="list-style-type: none"> • Sitting in a seat or vehicle
Pass/Fail Criteria:	<p>Does the body armor lift off the shoulders of the participant? Does the soft armor sit on the lap/thighs of the participant? Does either side plate sit on lap/thigh or dig into hip of participant? Does the front plate sit on the lap/thigh of the participant?</p>
Data Collection:	<p>Measurement 1</p> <p>Note: Only one measurement was taken for this movement.</p>

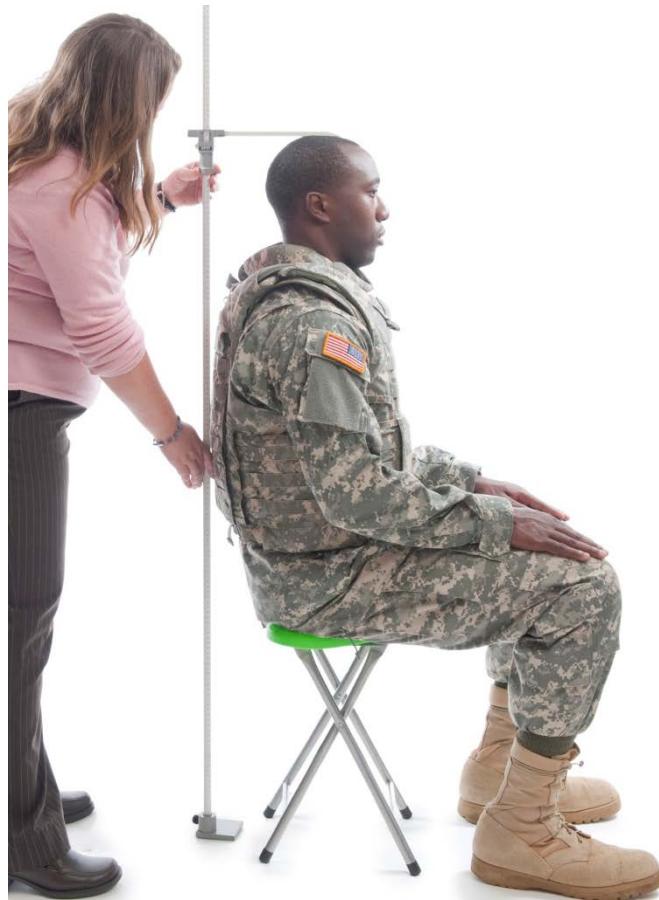


Figure 41: Seated Stature

Summary Statistics

Table 37: Seated Stature, measured in mm

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
N	111	68	67	95
Mean	1298.8	1300.6	1300.3	1310.2
Degradation of Mean	-	-0.1%*	-0.1%*	-0.8%*
Min	1218.0	1230.0	1228.0	1223.0
Max	1380.0	1373.0	1368.0	1388.0
SD	37.8	31.7	31.6	33.2
Skewness (Skew SD)	-0.05 (0.23)	-0.10 (0.29)	-0.10 (0.29)	-0.07 (0.25)

*Mean, Min, Max, and SD data in mm

SEATED STATURE

Table 38: Percentiles for Seated Stature scores

Percentile	mm			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	1221.0	1231.4	1230.6	1225.8
2 nd	1222.8	1236.3	1235.2	1233.0
3 rd	1230.3	1244.0	1241.8	1246.3
5 th	1233.5	1245.8	1250.3	1259.1
10 th	1246.0	1261.6	1259.2	1270.6
15 th	1258.0	1266.4	1272.4	1279.1
20 th	1265.0	1273.6	1275.2	1281.0
25 th	1275.0	1283.0	1279.0	1283.0
30 th	1282.0	1285.0	1285.0	1284.2
35 th	1286.0	1289.6	1288.1	1293.8
40 th	1289.0	1292.2	1290.0	1300.6
45 th	1295.0	1295.0	1294.4	1303.3
50 th	1296.0	1299.0	1298.0	1306.0
55 th	1301.0	1305.4	1300.6	1310.7
60 th	1307.0	1312.8	1304.6	1316.4
65 th	1314.0	1315.2	1312.9	1322.1
70 th	1320.0	1319.6	1320.0	1328.6
75 th	1327.0	1325.0	1326.0	1336.0
80 th	1335.0	1330.0	1330.8	1337.2
85 th	1338.5	1334.8	1337.2	1342.9
90 th	1347.0	1339.4	1340.0	1347.6
95 th	1362.0	1345.0	1346.4	1358.1
97 th	1366.0	1346.9	1351.1	1375.2
98 th	1369.2	1358.5	1355.8	1376.1
99 th	1379.0	1367.6	1361.4	1377.7

TRUNK FLEXION - SEATED (Bending at Waist-Sitting, Chair)

Description

Area of Body:	Hip, torso
Equipment Needed:	<ul style="list-style-type: none"> • Chair (seat pan height = 44 cm) placed on platform • Platform (to place chair on) with flat surface <ul style="list-style-type: none"> ◦ At least 400 mm high (Height of the platform is subtracted during the data manipulation.) ◦ Wide enough to provide support for the chair ◦ Attached vertical scale (optional) to front face/wall of platform • Measuring stick/ruler or anthropometer
Movement Sequence:	<ol style="list-style-type: none"> 1. Test participant sits in chair that is on raised platform. <ol style="list-style-type: none"> a. Feet should be approximately a shoulder width apart and should be as flat as possible, depending on design of platform. <ol style="list-style-type: none"> i. Knees should be at approximately 90°. 2. Participant bends at the waist as far down as possible (attempting to touch the floor). 3. Participant's hands are outside feet/legs, and the palms face behind the body.
Measurement Sequence:	<ol style="list-style-type: none"> 1. The distance between the longest fingertip of the right hand and the floor is measured. 2. Participant sits on raised platform to allow for flexibility/movement beyond toes.
Cautions:	<ul style="list-style-type: none"> • Chair legs must be on ground/platform. • Test participant's body/buttocks should not lift off seat. • Test participant should reach on the outside of their feet. • Anthropometer should be straight, perpendicular to the floor.
Potential Causes of Restriction:	<ul style="list-style-type: none"> • Vest is long. • Weight of armor is not well distributed. • Vest is rigid in the stomach/chest area. • Side and/or front plate sits low on torso and/or is long. • Armor chest breadth is wide and/or is same width as front plate. • Shoulder strap is wide.

TRUNK FLEXION - SEATED

Real World Equivalents:	<ul style="list-style-type: none"> • Bending down to pick up an item off the floor • High crawl movement
Controlled Movement Components:	<ul style="list-style-type: none"> • Thoracic/lumbar lateral flexion
Data Collection:	<p>Measurement 1-platform height Measurement 2-platform height Measurement 3-platform height Mean 1-3</p> <p>Each observed measurement has the height of the platform subtracted from it, allowing all measurements to be compared, even if the height of the platform varies. This forces a “0” point at the bottom of the individual’s feet. Therefore, many participants will have a negative score. These three derived measurements are used to calculate a mean, which is the score.</p> <p>Add 10 mm if anthropometer is used, to account for the width of the bar.</p>
Reminder:	<ul style="list-style-type: none"> • Higher scores indicate poorer performance. • A score below “0” (i.e., negative) indicates that the participant reached farther than the level of the bottom of his/her feet. • During the first phase of testing, several test participants had to be dropped because they were able to easily reach the floor from the height of the platform; therefore, N’s were smaller for this movement than for the other movements.



Figure 42: Trunk Flexion - Seated

TRUNK FLEXION - SEATED

Summary Statistics

Table 39: Trunk Flexion - Seated, measured in mm

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
N	92	67	67	95
Mean	-137.3	-108.1	-111.2	-54.8
Degradation of Mean	-	21.3%	19.0%	60.1%
Max	36.7	30.7	15.3	103.7
Min	-305.3	-264.7	-237.0	-217.0
SD	60.6	62.7	56.8	60.4
Skewness (Skew SD)	0.04 (0.25)	-0.20 (0.29)	-0.26 (0.29)	-0.12 (0.25)

*Mean, Min, Max, and SD data in mm

Note: The smaller the score/measurement, the better the performance. A score of 0 means the participants could reach to the level of the bottom of their feet. A negative score means that the participants could reach farther than the level of the bottom of their feet.

TRUNK FLEXION - SEATED

Table 40: Percentiles for Trunk Flexion - Seated scores

Percentile	mm			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	11.8	10.3	-9.1	67.0
2 nd	-18.8	-1.2	-23.5	54.7
3 rd	-30.6	-4.1	-27.2	52.5
5 th	-43.0	-11.4	-32.5	52.0
10 th	-66.3	-24.6	-41.8	20.6
15 th	-80.4	-43.1	-54.6	1.7
20 th	-88.4	-57.8	-57.3	-5.7
25 th	-98.2	-71.2	-65.7	-16.5
30 th	-103.3	-80.3	-73.2	-23.8
35 th	-108.3	-86.3	-81.2	-42.1
40 th	-120.1	-96.6	-87.5	-50.0
45 th	-125.7	-98.9	-101.2	-50.0
50 th	-144.9	-103.2	-109.3	-50.0
55 th	-155.0	-108.1	-120.5	-54.9
60 th	-159.4	-117.2	-128.3	-64.3
65 th	-164.0	-122.7	-134.2	-77.2
70 th	-166.9	-132.5	-145.2	-82.7
75 th	-172.0	-150.4	-153.9	-90.9
80 th	-182.6	-158.1	-161.8	-94.3
85 th	-196.3	-170.8	-164.5	-107.1
90 th	-211.5	-191.6	-172.0	-135.5
95 th	-216.8	-218.6	-224.2	-158.6
97 th	-254.0	-222.0	-229.1	-186.5
98 th	-266.0	-225.5	-231.5	-187.9
99 th	-286.2	-239.6	-234.2	-194.2

Note: These percentiles have been reversed because the smaller the number the better the performance.

TAKE A KNEE

Description

Area of Body:	Lower body
Equipment Needed:	None
Movement Sequence:	<ol style="list-style-type: none"> 1. From the standing position, test participant drops down so one knee and shin are on the ground and the other leg is bent at a 90° angle with the foot flat on the ground. 2. Torso can be either upright or bent forward, arms resting on the raised knee/thigh.
Measurement Sequence:	No objective measurement
Cautions:	-
Potential Causes of Restriction:	<ul style="list-style-type: none"> • Armor chest breadth is wide and/or is same width as front plate • Side plates and/or front plate are positioned low on the torso or are too long. • Vest is long.
Real World Equivalents:	<ul style="list-style-type: none"> • Taking a knee to rest • Getting into firing position • Tying the laces of a boot
Controlled Movement Components:	<ul style="list-style-type: none"> • Upper leg/hip flexion
Pass/Fail Criteria:	<p>Does armor hinder balance? Does armor lift off body? Does armor touch the legs/lap? Does armor dig into stomach?</p>

TAKE A KNEE



Figure 43: Take a Knee

HIGH KNEE/KNEE LIFT

Description

Area of Body:	Torso, lower body
Plane:	Sagittal
Equipment Needed:	<ul style="list-style-type: none"> • Wall scale • Measuring block
Movement Sequence:	<ol style="list-style-type: none"> 1. Test participant stands with his/her right side facing a wall. 2. Test participant lifts his/her right knee as high as possible <ol style="list-style-type: none"> a. Leg may be kicked out in whatever direction (side or front) is necessary for the participant to gain the most height. 3. Participant may put a hand on the wall for support. 4. Participant should hold knee at that maximum height. 5. Test participant is allowed to bend knees/back.
Measurement Sequence:	<ol style="list-style-type: none"> 1. Place the block at the top of the knee cap, where the knee meets the muscle, so that it touches both the wall scale and the knee.
Cautions:	<ul style="list-style-type: none"> • Block is parallel to the floor
Potential Causes of Restriction:	<ul style="list-style-type: none"> • Armor is long. • Side plates and/or front plate sits low on body and/or is long.
Real World Equivalents:	<ul style="list-style-type: none"> • Stepping over a large object, such as a guard rail. • Moving through a wall breach • Stepping up onto a high step • Climbing a ladder • Stepping into an aircraft or vehicle
Controlled Movement Components:	<ul style="list-style-type: none"> • Hip flexion
Data Collection:	<p>Measurement 1 Measurement 2 Measurement 3 Mean 1-3</p> <p>There is no manipulation of the data. Three measurements are taken, and a mean is calculated and used as the score.</p>

HIGH KNEE/KNEE LIFT



Figure 44: High Knee/Knee Lift

HIGH KNEE/KNEE LIFT

Summary Statistics

Table 41: High Knee/Knee Lift, measured in mm

Statistic*	BAPL 0: ACU only	BAPL 1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
N	113	67	67	95
Mean	1167.0	1143.3	1153.8	1104.0
Degradation of Mean	-	2.0%	1.1%	5.4%
Min	884.3	911.3	912.3	745.7
Max	1373.7	1325.7	1391.0	1337.0
SD	88.0	93.0	88.2	113.6
Skewness (Skew SD)	-0.12 (0.23)	-0.10 (0.29)	-0.14 (0.29)	-0.47 (0.25)

*Mean, Min, Max, and SD data in mm

HIGH KNEE/KNEE LIFT

Table 42: Percentiles for High Knee/Knee Lift scores

Percentile	mm			
	BAPL 0: ACU only	BAPL1: IOTV with soft armor only	BAPL 3: Plate Carrier with front, back, & side plates	BAPL 5: IOTV with front, back, & side plates
1 st	964.7	956.2	942.0	844.4
2 nd	989.9	985.7	976.5	856.5
3 rd	1032.2	1000.0	1016.1	877.0
5 th	1042.1	1006.7	1035.1	903.4
10 th	1059.8	1032.8	1046.8	971.0
15 th	1075.8	1038.4	1062.2	1003.3
20 th	1098.6	1052.1	1070.5	1010.6
25 th	1107.3	1066.5	1093.0	1020.2
30 th	1119.5	1079.8	1099.3	1043.9
35 th	1131.1	1096.5	1102.5	1056.9
40 th	1139.0	1111.6	1129.1	1085.9
45 th	1148.3	1142.7	1148.3	1107.4
50 th	1156.0	1151.0	1157.3	1118.3
55 th	1171.3	1167.4	1172.7	1134.1
60 th	1185.1	1188.0	1188.9	1144.2
65 th	1201.2	1194.7	1202.2	1164.6
70 th	1219.4	1199.9	1218.6	1171.3
75 th	1238.7	1218.8	1222.4	1186.0
80 th	1245.6	1232.0	1226.6	1193.0
85 th	1261.0	1239.7	1234.8	1214.1
90 th	1274.5	1260.6	1255.0	1239.7
95 th	1297.6	1277.2	1263.9	1254.6
97 th	1328.9	1303.4	1303.1	1283.2
98 th	1335.2	1308.1	1305.7	1320.8
99 th	1360.6	1315.4	1335.6	1322.6

BOX LIFT

Description

Area of Body:	Whole body
Equipment Needed:	<ul style="list-style-type: none"> Medium sized box or box like object of negligible weight (e.g., trash can)
Movement Sequence:	<ol style="list-style-type: none"> Test participant is in standing position with feet a shoulder width apart Test participant bends down, bending at the waist and knees, and picks up the box, holding it at the sides. Test participant lifts the box to overhead height (as high as possible)
Measurement Sequence:	No objective measurement
Cautions:	-
Potential Causes of Restriction:	<ul style="list-style-type: none"> Vest is long. Arm hole opening is narrow. Armor chest breadth is wide and/or is same width as front plate. Shoulder strap is wide.
Real World Equivalents:	<ul style="list-style-type: none"> Moving ammo cans or other items
Controlled Movement Components:	<ul style="list-style-type: none"> Thoracic/lumbar spine rotation Upper arm/shoulder abduction, forward flexion extension, forward cross body extension Overhead fingertip reach Upper leg/hip flexion
Pass/Fail Criteria:	<p>Is restriction caused by the width of the shoulder strap?</p> <p>Does the soft armor dig into the thighs?</p> <p>Does the side plate dig into the thighs?</p> <p>Does the side plate dig into the hips?</p> <p>Does the armor lift up, covering the chin?</p>

BOX LIFT



Figure 45: Overhead Box Lift

AIM M4 RIFLE IN PRONE POSITION - UNSUPPORTED

Description

Area of Body:	Whole body
Equipment Needed:	<ul style="list-style-type: none"> • M4 or M16 weapon
Movement Sequence:	<ol style="list-style-type: none"> 1. Participant lies flat on stomach <ol style="list-style-type: none"> a. Legs should be behind the participant, in a v-shape, with a bend in one or both knees. 2. Rifle butt is brought against shoulder to allow participant to look down the sight of the weapon. <ol style="list-style-type: none"> a. Elbow should be placed on ground to provide support. 3. Index finger is on trigger; supporting hand is supporting stock of weapon. 4. Participant points rifle toward the target or straight ahead. 5. Participant aims rifle at a second higher target. <ol style="list-style-type: none"> a. Second target should be high enough to require participant to raise his/her head. b. Elbow can be raised off the ground, if needed.
Measurement Sequence:	No objective measurement
Cautions:	-
Potential Causes of Restriction:	<ul style="list-style-type: none"> • Shoulder pocket is covered by armor and/or plate. • Shoulder strap is wide. • Armor chest breadth is wide and/or is same width as front plate. • Amount of space (bulk of armor) between the participant's skin and where the butt stock of the weapon pushes the position of the weapon out, making it difficult for some participants to reach. • Rigidity of back and/or front plate does not allow for curvature of spine/torso. • Collar is too high. • Vest is long. • Side and/or front plates sit low on body and/or are long.
Real World Equivalents:	<ul style="list-style-type: none"> • Operating weapon in the prone position
Controlled Movement Components:	<ul style="list-style-type: none"> • Upper arm/shoulder forward flexion extension and cross body extension • Forward extended reach • Upper leg/hip flexion (in some cases)

AIM M4 RIFLE – PRONE POSITION

Pass/Fail Criteria:	<p>Is the participant able to sight the weapon?</p> <ul style="list-style-type: none">- Can participant lift head back/up far enough?- Can participant bring weapon close enough to head/cheek?- Can participant get the proper neck angle to sight the weapon?- Is participant's cheek positioned at the correct location on the weapon? Too far forward? Too far back? <p>Is the participant able to position the butt stock correctly at first?</p> <ul style="list-style-type: none">- Without adjusting armor?- Without multiple attempts? <p>Is participant able to support the weapon with non-firing hand?</p> <p>Is participant able to get into a steady firing position?</p>
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(a)



(b)



Figure 46: Aim M4 Rifle in Prone Position - Unsupported. (a) Aiming straight ahead; (b) Aiming at high object

AIM M4 RIFLE IN KNEELING POSITION - SUPPORTED

Movement Description

Area of Body:	Whole body
Equipment Needed:	<ul style="list-style-type: none"> • M4 or M16 weapon
Movement Sequence:	<ol style="list-style-type: none"> 1. From a standing position, test participant drops to one knee <ol style="list-style-type: none"> a. Firing side knee (same side as weapon is shouldered on) goes down on the ground. b. Opposite knee is at ~90-110° with foot on ground. c. Supporting arm/elbow is resting on upright knee. d. Trigger arm bicep is parallel to torso, and trigger forearm is pulled tight to the bicep. 2. Rifle butt is brought against shoulder to allow participant to look down the sight of the weapon. 3. Trigger hand is on trigger, and other hand is supporting stock of weapon. 4. Rifle is pointed toward the target or straight ahead.
Measurement Sequence:	No objective measurement
Cautions:	-
Potential Causes of Restriction:	<ul style="list-style-type: none"> • Shoulder pocket is covered by armor and/or plate. • Armor chest breadth is wide and/or is same width as front plate. • Amount of space (bulk of armor) between participant's skin and where the butt stock of the weapon pushes the position of the weapon out, making it difficult for some participants to reach. • Rigidity of back and/or front plate does not allow for curvature of spine/torso. • Collar is too high. • Vest is long. • Side and/or front plates sit low on body and/or are long.
Real World Equivalents:	<ul style="list-style-type: none"> • Operating weapon in the kneeling position
Controlled Movement Components:	<ul style="list-style-type: none"> • Upper arm/shoulder forward flexion extension and cross body extension • Forward extended reach • Upper leg/hip flexion • Trunk flexion

AIM M4 – KNEELING

Pass/Fail Criteria:	<p>Is participant able to sight the weapon?</p> <ul style="list-style-type: none">- Can participant lift head back/up far enough?- Can participant bring weapon close enough to head/cheek?- Can participant get the proper neck angle to sight the weapon?- Is participant's cheek positioned at the correct location on the weapon? Too far forward? Too far back? <p>Is participant able to position the butt stock correctly at first?</p> <ul style="list-style-type: none">- Without adjusting armor?- In a single attempt? <p>Is participant able to support the weapon with non-firing hand?</p> <p>Is participant able to get into a steady firing position?</p> <p>Is participant able to place his/her elbow on his/her knee?</p>
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Figure 47: Aim M4 Rifle in Kneeling Position - Supported

AIM M4 RIFLE IN STANDING POSITION - UNSUPPORTED

Movement Description

Area of Body:	Whole body
Equipment Needed:	<ul style="list-style-type: none"> • M4 or M16 weapon
Movement Sequence:	<ol style="list-style-type: none"> 1. Participant is in a standing position (but not anthropometric standing position), with either his/her feet shoulder width apart or with one foot slightly in front of the other and shoulder width apart. 2. Rifle butt is brought against shoulder to allow participant to look down the sight of weapon. 3. Trigger finger is on trigger, and other hand is supporting stock of weapon. 4. Rifle is pointed toward the target or straight ahead.
Measurement Sequence:	No objective measurement
Cautions:	-
Potential Causes of Restriction:	<ul style="list-style-type: none"> • Shoulder pocket is covered by armor and/or plate. • Armor chest breadth is wide and/or is same width as front plate. • Amount of space (bulk of armor) between the participant's skin and where the butt stock of the weapon pushes the position of the weapon out, making it difficult for some participants to reach. • Rigidity of back and/or front plate does not allow for curvature of spine/torso. • Collar is too high.
Real World Equivalents:	<ul style="list-style-type: none"> • Operating weapon in the standing position
Controlled Movement Components:	<ul style="list-style-type: none"> • Upper arm/shoulder forward flexion extension and cross body extension • Forward extended reach
Pass/Fail Criteria:	<p>Is participant able to sight the weapon?</p> <ul style="list-style-type: none"> - Can participant lift head back/up far enough? - Can participant bring weapon close enough to head/cheek? - Can participant get the proper neck angle to sight the weapon? - Is participant's cheek positioned at the correct location on the weapon? Too far forward? Too far back? <p>Is the participant able to position the butt stock correctly at first?</p> <ul style="list-style-type: none"> - Without adjusting armor? - Without multiple attempts? <p>Is participant able to support the weapon with non-firing hand?</p> <p>Is participant able to get into a steady firing position?</p>

AIM M4 - STANDING, UNSUPPORTED



Figure 48: Aim M4 Rifle in Standing Position - Unsupported

AIM 9MM PISTOL IN STANDING POSITION - UNSUPPORTED

Description

Area of Body:	Whole body
Equipment Needed:	<ul style="list-style-type: none"> • 9mm weapon
Movement Sequence:	<ol style="list-style-type: none"> 1. Test participant stands with a feet shoulder width apart, one foot slightly forward. 2. Arms are raised to shoulder height and extended. 3. There is a slight bend in the elbows. 4. In this basic position, participant tracks up, down, left and right by rotating their shoulders, waist, and neck.
Measurement Sequence:	No objective measurement
Cautions:	-
Potential Causes of Restriction:	<ul style="list-style-type: none"> • Armor chest breadth is wide and/or is same width as front plate. • Rigidity of back and/or front plate does not allow for curvature of spine/torso. • Collar is too high.
Real World Equivalents:	<ul style="list-style-type: none"> • Aiming and operating a handgun from a high position targeting down low, from a low position targeting up high (i.e., roof top), etc.
Controlled Movement Components:	<ul style="list-style-type: none"> • Upper arm/shoulder forward flexion extension and cross body extension • Forward extended reach • Cervical rotation • Ventral-dorsal cervical flexion
Pass/Fail Criteria:	<p>Is participant able to sight the weapon?</p> <ul style="list-style-type: none"> - Can participant position head back/up far enough? <p>Is participant able to lift his/her arms to the correct height?</p> <p>Is participant able to pull arms in close enough to body?</p> <p>Is participant able to get into a steady firing position?</p>

AIM 9mm - STANDING, UNSUPPORTED

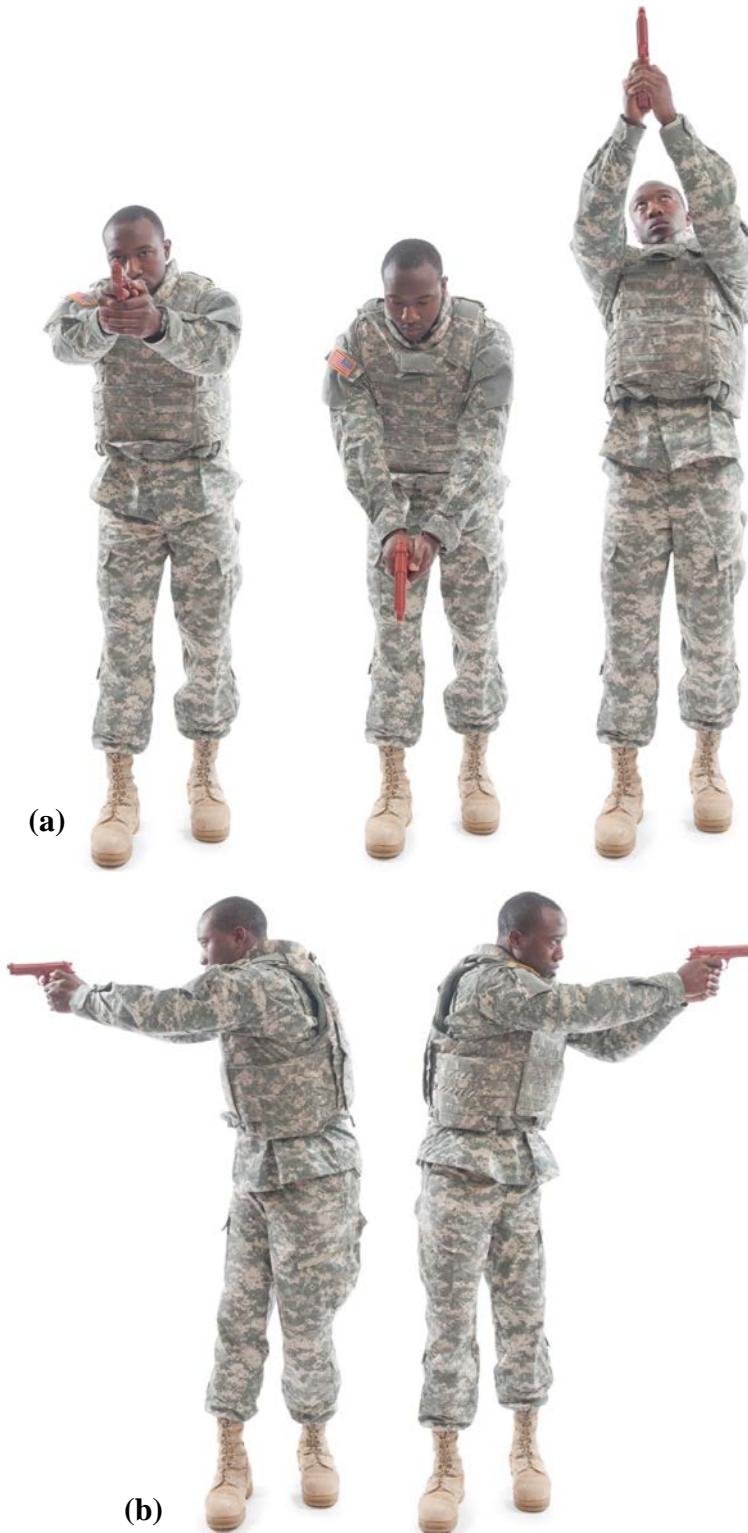


Figure 49: Aim 9mm Pistol in Standing Position - Unsupported. (a) Aiming straight on, down low, and up high; (b) Aiming left and right

5. CONCLUSIONS

The methodologies outlined in this document can be used to direct and aid testers in the standardized measurement of ROM (including reaches) in clothing and individual equipment. As with any other scientific measurement, it is important that controlled measurements be conducted with great attention to detail. With ROM measurement, the test participant, measurer, and data collector all have very important responsibilities to ensure that the movement is performed and the measurement is taken correctly. The test participants must perform the movements following the directions as accurately as they are able to, fully utilizing their individual active ROM. The measurer must ensure that the test instrument is utilized properly by placing it in the correct location on the body. The data collector must properly record the measurement reading by the measure and observe both the test participants (to ensure they make the movements properly) and the measurers (to ensure they take the measurements properly). By following a standard set of methods, the variability between measurements and test participants can be minimized. With ROM there will always be some variability due to differences in human performance; however, they should be limited as much as possible.

While the methodology was originally designed to be used only when the participants wear body armor, it has also proved useful for assessing the ROM of a variety of different encumbered configurations. While this document does not outline the expected ROM scores for all the body armor configurations, it does outline what the scores should be for a wide variety of military personnel in their duty uniforms and in some standard and commonly used body armor configurations. Additionally, these baseline scores give goals for clothing and individual equipment designers, in that users should be able to perform these same movements and get similar results if the clothing and individual equipment does not provide any restriction or interference to their movements. As additional encumbered ROM data become available, if the same methodologies are followed, data from different studies can be combined to allow for even greater knowledge about the effects of different clothing and individual equipment on Soldiers. Additionally, this information can be used to assist in describing Soldier performance, workstation design, and digital modeling and validation and for comparing data sets between different nations or groups of participants.

This document reports research undertaken at the U.S. Army Natick Soldier Research, Development and Engineering Center, Natick, MA, and has been assigned No. NATICK/TR- 13/033 in a series of reports approved for publication.

6. WORKS CITED

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APPENDIX A

DATA COLLECTION FORMS

(Reprint of original)

**Body Armor Range of Motion Assessment
Data Sheet**



TP ID: _____

Body Armor System: Baseline-0 IOTV-Soft 1 PC,F,B,S-3 IOTV-F,B,S-5

Very Poor	Poor	Neutral	Good	Very Good
(1)	(2)	(3)	(4)	(5)

Armor Item	Best Available Size	Bulk (mm) (wall to Acromion)	Fit Rating	Comments
			(1) (2) (3) (4) (5)	

Anthropometry Station

Movement	1 st	2 nd	3 rd	Rating
Stature – Standing (with boots)				(1) (2) (3) (4) (5)
Comments:	Are you being pulled <i>forward</i> by the armor? <input checked="" type="radio"/> (Y) <input type="radio"/> (N) Are you being pulled <i>backward</i> by the armor? <input checked="" type="radio"/> (Y) <input type="radio"/> (N)			
Stature - Seated				(1) (2) (3) (4) (5)
Comments:	Does the body armor lift off the shoulders? <input checked="" type="radio"/> (Y) <input type="radio"/> (N) Does the armor lift up covering your chin? <input checked="" type="radio"/> (Y) <input type="radio"/> (N) Does the armor sit on the lap/thighs of the subject? (all that apply) Soft <input checked="" type="radio"/> (1) <input type="radio"/> (2) <input type="radio"/> (3) <input type="radio"/> (4) <input checked="" type="radio"/> (5) Front Side <input type="radio"/> (1) <input checked="" type="radio"/> (2) <input type="radio"/> (3) <input type="radio"/> (4) <input checked="" type="radio"/> (5) Side Does the side plate dig into the hip bone? <input checked="" type="radio"/> (Y) <input type="radio"/> (N) <input checked="" type="radio"/> (X)			

**Body Armor Range of Motion Assessment
Data Sheet**



TP ID: _____

Body Armor System: Baseline-0 IOTV-Soft 1 PC,F,B,S-3 IOTV-F,B,S-5

Station A

Restriction Ratings				
No Interference or degradation	Slight Interference; easily worked around	Moderate interference, difficult, but able to work around	Severe interference, very difficult to work-around; unacceptable	Extreme interference, unable to work-around; unacceptable
(1)	(2)	(3)	(4)	(5)
Movement	1st	2nd	3rd	Rating
Upper Arm/Shoulder Abduction				(1) (2) (3) (4) (5)
Comments:				
Upper Arm/Shoulder Forward Extension				(1) (2) (3) (4) (5)
Comments:				
Upper Arm/Shoulder Backward Extension				(1) (2) (3) (4) (5)
Comments:				
Upper Leg/Hip Flexion				(1) (2) (3) (4) (5)
Comments:				
Cervical Rotation				(1) (2) (3) (4) (5)
Comments:				
Upper Arm/Shoulder Cross Body Extension				(1) (2) (3) (4) (5)
Comments:				
Thoracic/Lumbar Spine Rotation				(1) (2) (3) (4) (5)
*Put dot marker on Acromion				
Comments:				
Ventral-Dorsal Cervical Flexion				(1) (2) (3) (4) (5)
Comments:				

Body Armor Range of Motion Assessment Data Sheet



TP ID: _____

Body Armor System: Baseline-0 IOTV-Soft 1 PC,F,B,S-3 IOTV-F,B,S-5

Station B

Restriction Ratings							
No Interference or degradation	Slight Interference; easily worked around		Moderate interference, difficult, but able to work around	Severe interference, very difficult to work-around; unacceptable	Extreme interference, unable to work-around; unacceptable		
(1)	(2)	(3)	(4)	(5)	(6)		
Movement	1st	2nd	3rd	Rating			
Thoracic/Lumbar Spine Lateral Flexion	Stand +10	Reach +10	Stand +10	Reach +10	Stand +10	Reach +10	(1) (2) (3) (4) (5) (6)
Comments:							
Trunk Flexion - Standing							(1) (2) (3) (4) (5)
Comments:							
Trunk Flexion - Seated							(1) (2) (3) (4) (5)
Comments:							
Overhead Fingertip Reach - Standing							(1) (2) (3) (4) (5)
Comments:							
Forward Extended Reach - Standing							(1) (2) (3) (4) (5)
Minus Bulk Measurement							
Comments:							
Cross Body Reach - Sitting							(1) (2) (3) (4) (5)
Comments:							
High Knees							(1) (2) (3) (4) (5)
Comments:							

Body Armor Range of Motion Assessment Data Sheet



TP ID: _____

Body Armor System: Baseline-0 IOTV-Soft 1 PC,F,B,S-3 IOTV-F,B,S-5

Station C

Restriction Ratings																																																																																																																							
No Interference or degradation	Slight Interference; easily worked around	Moderate interference, difficult, but able to work around	Severe interference, very difficult to work-around; unacceptable	Extreme interference, unable to work-around; unacceptable																																																																																																																			
(1)	(2)	(3)	(4)	(5)																																																																																																																			
Movement	1st	2nd	3rd	Rating																																																																																																																			
Walk Forward 5 Steps				(1) (2) (3) (4) (5)																																																																																																																			
Comments:																																																																																																																							
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Body Armor Range of Motion Assessment Data Sheet



TP ID: _____

Body Armor System: Baseline-0 IOTV-Soft 1 PC,F,B,S-3 IOTV-F,B,S-5

Activity	Restriction Rating					Discomfort?	
Take a Knee	(1) (2) (3) (4) (5)					(Y)	(N)
Comments: Note where restriction is and what part of equipment is the cause:							
Does the subject loose balance when getting up/down?	(Y)	(N)					
Does the armor lift up covering your chin?	(Y)	(N)					
Does the armor sit on the lap/thighs? (all that apply)	(1) Soft	(2) Side	(3) Front	(4) Front	(5) Front		
Does the armor dig into stomach?	(1) Soft	(2) Front	(3) Front	(4) Front	(5) Front		

Activity	Restriction Rating					Discomfort?	
Box Lift	(1) (2) (3) (4) (5)					(Y)	(N)
Comments: Note where restriction is and what part of equipment is the cause:							
Is restriction caused by the width of the shoulder strap?	(Y)	(N)					
Does the armor lift up covering your chin?	(Y)	(N)					
Does the armor sit on the lap/thighs? (all that apply)	(1) Soft	(2) Side	(3) Front	(4) Front	(5) Front		
Does the armor dig into stomach?	(1) Soft	(2) Front	(3) Front	(4) Front	(5) Front		

Activity	Restriction Rating					Discomfort?	
Target Acquisition: Standing M4	(1) (2) (3) (4) (5)					(Y)	(N)
Comments: Note where restriction is and what part of equipment is the cause:							
Is the subject able to sight the weapon?	(Y)	(N)					
- Can they bring their weapon close enough to their head/cheek?	(Y)	(N)					
- Is their cheek positioned at the correct location on the weapon?	(1) OK	(2) Forward	(3) Back				
Able to get into a steady firing position?	(Y)	(N)					
Able to position the butt stock correctly at first?	(Y)	(N)					
- If No, without adjusting armor?	(Y)	(N)					
Is the subject able to support the weapon with their non-firing hand?	(Y)	(N)					

Body Armor Range of Motion Assessment Data Sheet



TP ID: _____

Body Armor System: Baseline-0 IOTV-Soft 1 PC,F,B,S-3 IOTV-F,B,S-5

Activity	Restriction Rating	Discomfort?	
Target Acquisition: Kneeling M4	(1) (2) (3) (4) (5)	(Y)	(N)
Comments: Note where restriction is and what part of equipment is the cause:			
Is the subject able to sight the weapon?	(Y)	(N)	
- Can they bring their weapon close enough to their head/cheek?	(Y)	(N)	
- Is their cheek positioned at the correct location on the weapon?	(1) OK	(2) Forward	(3) Back
Able to get into a steady firing position?	(Y)	(N)	
Able to position the butt stock correctly at first?	(Y)	(N)	
- If No, without adjusting armor?	(Y)	(N)	
Is the subject able to support the weapon with their non-firing hand?	(Y)	(N)	

Activity	Restriction Rating	Discomfort?	
Target Acquisition: Prone, Unsupported M4	(1) (2) (3) (4) (5)	(Y)	(N)
Comments: Note where restriction is and what part of equipment is the cause:			
Is the subject able to sight the weapon?	(Y)	(N)	
- Can they bring their weapon close enough to their head/cheek?	(Y)	(N)	
- Is their cheek positioned at the correct location on the weapon?	(1) OK	(2) Forward	(3) Back
Able to get into a steady firing position?	(Y)	(N)	
Able to position the butt stock correctly at first?	(Y)	(N)	
- If No, without adjusting armor?	(Y)	(N)	
Is the subject able to support the weapon with their non-firing hand?	(Y)	(N)	

Activity	Restriction Rating	Discomfort?	
Target Acquisition: Standing M9mm	(1) (2) (3) (4) (5)	(Y)	(N)
Comments: Note where restriction is and what part of equipment is the cause:			
Is the subject able to sight the weapon?	(Y)	(N)	
- Can they position their head back/up far enough?	(Y)	(N)	
Is the subject able to lift his/her arms to the correct height?	(Y)	(N)	
Is the subject able to pull arms in close enough to body?	(Y)	(N)	
Is the subject able to get into a steady firing position?	(Y)	(N)	